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FINAL

Work Plan for a Demonstration of Remediation by Natural Attenuation for Groundwater at OU 1



**Hill Air Force Base
Ogden, Utah**

Prepared For

**Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas**

and

**Hill Air Force Base
Ogden, Utah**

November 1996

AQM01-01-0316

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FINAL
WORK PLAN FOR A DEMONSTRATION OF
REMEDATION BY NATURAL ATTENUATION
FOR GROUNDWATER AT OU 1

at

HILL AIR FORCE BASE, UTAH

November 1996

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

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ACRONYMS AND ABBREVIATIONS

°C	degrees centigrade
°F	degrees Fahrenheit
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
bgl	below ground level
BNAE	base-neutral acid-extractable
BTEX	benzene, toluene, ethylbenzene, xylenes
CA	chloroethane
CAH	chlorinated aliphatic hydrocarbon
CDP	Chemical Disposal Pit
cm/sec	centimeters per second
CPT	cone penetrometer test
CSR	CalScience Research, Inc.
DCA	dichloroethane
DCB	dichlorobenzene
DCE	dichloroethene
DO	dissolved oxygen
ES	Engineering-Science, Inc.
ft/day	feet per day
ft ² /day	square feet per day
ft/ft	feet per foot
ft/min	feet per minute
FTA	Fire Training Area
HARM	Hazardous Assessment Rating Methodology
HDPE	high density polyethylene
ID	inside diameter
IRP	Installation Restoration Program
IWTP	industrial wastewater treatment plant
JMM	James M. Montgomery, Consulting Engineers, Inc.
L/min	liters per minute
LCS	laboratory control sample
LF	Landfill
LMB	laboratory method blank
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MCL	maximum concentration limit
MEK	methyl ethyl ketone
mg/kg	milligrams per kilogram

mg/L	milligrams per liter
msl	mean sea level
mV	millivolt
NPL	National Priority List
NRMRL	National Risk Management Research Laboratory
OD	outside diameter
ORD	Office of Research and Development
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
OVM	Organic Vapor Meter
Parsons ES	Parsons Engineering Science, Inc.
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PID	photoionization detector
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
Radian	Radian Corporation
RAP	remedial action plan
redox	reduction/oxidation
RI	Remedial Investigation
RNA	remediation by natural attenuation
SAIC	Science Applications International Corporation
SDWA	Safe Drinking Water Act
TCA	trichloroethane
TCE	trichloroethene
TCLP	toxicity characteristic leaching procedure
TD	total depth
TDS	total dissolved solids
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
WOST	waste oil storage tank
WPOP	waste phenol/oil pit

SECTION 1

INTRODUCTION

This work plan, prepared by Parsons Engineering Science, Inc. (Parsons ES), presents the scope of work required for the collection of data necessary to demonstrate remediation by natural attenuation (RNA) of groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) at a portion of Operable Unit 1 (OU 1), located at Hill Air Force Base (AFB), Utah. Because other contaminants present at this site are found in relatively low concentrations, this demonstration will focus on the CAH plume at OU 1. Hydrogeologic and groundwater chemical data collected under this program can also be used to evaluate various engineered remedial options; however, this work plan is oriented toward the collection of hydrogeologic data to be used as input into groundwater flow and solute transport models in support of RNA with long-term monitoring (LTM) for restoration of groundwater contaminated with CAHs. At OU 1, some remedial actions already are planned or in pilot-testing stages, such as soil vapor extraction and bioventing.

As used in this report, RNA refers to a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER) define natural attenuation as:

The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

As suggested by this definition, mechanisms for natural attenuation of CAHs include advection, dispersion, dilution from recharge, sorption, volatilization, abiotic chemical transformation, and biodegradation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. During biodegradation, indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the engineered addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

RNA is advantageous for the following reasons:

- Contaminants are transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), not just transferred to another phase or location within the environment;
- Current pump-and-treat technologies are energy-intensive and generally not as effective in reducing residual contamination;
- The process is nonintrusive and allows continuing use of infrastructure during remediation;
- Engineered remedial technologies may pose a greater risk to potential receptors than RNA (e.g., contaminants may be transferred into another medium during remediation activities); and
- RNA is less costly than conventional, engineered remedial technologies.

Natural attenuation has the following potential limitations:

- natural attenuation is subject to natural and institutionally-induced changes in local hydrogeologic conditions, including changes in groundwater gradients/velocity, pH, electron acceptor concentrations, electron donor concentrations, or potential future contaminant releases;
- aquifer heterogeneity may complicate site characterization, evaluation, and implementation of natural attenuation;
- time frames for completion may be relatively long; and
- intermediate products of biodegradation (e.g., vinyl chloride) are often more toxic than the original contaminant.

Evaluation of RNA for OU 1 at Hill AFB will involve completion of several tasks, which are described in the following sections.

This work plan was developed based on discussions among representatives from Hill AFB, regulatory agencies (the State of Utah and the USEPA), the Air Force Center for Environmental Excellence (AFCEE), the USEPA National Risk Management Research Laboratory (NRMRL), and Parsons ES. Amongst these discussions was a roundtable meeting among representatives of AFCEE, Hill AFB, regulators, NRMRL personnel, and Parsons ES personnel, held at Hill AFB on April 3, 1996, to discuss a site-specific approach for this RNA evaluation. In addition, available site characterization data were reviewed during the preparation of this work plan. All field work will follow the health and safety procedures presented in the program *Health and Safety Plan for Bioplume II Modeling Initiative* [Engineering-Science, Inc. (ES), 1993] and the site-specific addendum to the program Health and Safety Plan. This work plan was prepared for AFCEE and Hill AFB. This work is not intended to fulfill the requirements of a

contamination assessment report, a remedial action plan (RAP), or any other document specified in federal or state regulations; rather, it is provided for the use of the Base, its prime environmental contractors, and regulators as information to be used for future decision-making regarding this site, unless otherwise requested by AFCEE or the Base.

1.1 SCOPE OF CURRENT WORK PLAN

The ultimate objective of the work described herein is to provide a site-specific demonstration to support the use of RNA for groundwater contamination in conjunction with other remedial actions at OU 1. However, this project is part of a larger, broad-based initiative being conducted by AFCEE in conjunction with the USEPA NRMRL and Parsons ES to document and evaluate the biodegradation and resulting attenuation of solvents and fuel hydrocarbons dissolved in groundwater, and to model this degradation using numerical or analytical solute transport models. For this reason, the work described in this work plan is directed in part toward the collection of data in support of implementation of this initiative at this site. Other remedial actions being considered for this site include soil vapor extraction and bioventing. The effects of these actions on RNA will be considered.

The intent of this RNA demonstration program is to develop a systematic process for scientifically investigating and documenting naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objective of the program and this specific demonstration is to provide solid evidence of RNA of CAHs dissolved in groundwater so that this information can be used by Hill AFB to develop an effective groundwater remediation strategy for OU 1. As a result, these demonstrations are not necessarily intended to fulfill specific federal or state requirements regarding site assessments, RAPs, or other such mandated investigations and reports. A secondary goal of this multi-site initiative is to provide a database from multiple sites that demonstrates that natural processes of contaminant degradation often can reduce contaminant concentrations in groundwater below acceptable cleanup standards before potential receptor exposure pathways are completed.

This work plan describes the site characterization activities to be performed by personnel from Parsons ES and the Subsurface Protection and Remediation Division of the NRMRL [formerly the USEPA's Robert S. Kerr Environmental Research Laboratory] in support of the demonstration and the groundwater modeling effort. Field activities will be performed to evaluate the effectiveness of RNA in remediating the dissolved CAH plume at OU 1. The data collected during the demonstration will be used along with data from previous investigations to characterize contaminant and geochemical patterns at the site, and as input for groundwater flow and solute transport models to make predictions of the future concentrations and extent of contamination.

Site characterization activities in support of the demonstration will include: 1) determination of preferential contaminant migration and potential receptor exposure pathways; 2) soil sampling using Geoprobe® direct-push technology; 3) groundwater grab sampling using the Geoprobe®; 4) groundwater sampling from monitoring wells; and 5) aquifer testing, which may include downhole flow-meter testing. The materials and methods to accomplish these activities are described herein. Previously reported

site-specific data and data collected during the supplemental site characterization activities described in this work plan will be used to develop a conceptual model of contaminant transport and natural attenuation at the site. Following development of the conceptual model the data will be used as input for the groundwater flow and solute transport models. Where site-specific data are not available, conservative values for the types of aquifer materials present at the site will be obtained from widely accepted published literature and used for model input. Sensitivity analyses will be conducted for the parameters that are known to have the greatest influence on the model results, and where possible, the model will be calibrated using historical site data. Upon completion of the modeling, Parsons ES will provide technical assistance at regulatory negotiations to support RNA if the results of the sampling, data analysis, and modeling indicate that this approach is warranted. If it is shown that RNA is not an appropriate remedial option, Parsons ES will suggest another groundwater remedial technology on the basis of available data.

The expert panel that met on April 3, 1996, made generic recommendations for two additional studies to be conducted outside of the scope of Parsons ES's contract. The two studies include 1) a laboratory treatability study to determine the potential for aerobic biodegradation of dichloroethene (DCE), and 2) an evaluation of the natural attenuation and fate of CAHs volatilizing from groundwater or discharging to the surface from springs or seeps at the downgradient ends of CAH plumes at Hill AFB. Implementation of these studies is not within Parsons ES's scope, but other courses of action to address these issues are being investigated by other parties present at the April 3 meeting.

This work plan consists of six sections, including this introduction. Section 2 presents a review of available, previously reported, site-specific data and conceptual models for the site. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional site characterization data. Section 4 describes the quality assurance/quality control (QA/QC) measures to be used during this project. Section 5 describes the remedial option evaluation procedure and report format. Section 6 contains the references used in preparing this document. There are two appendices to this work plan. Appendix A summarizes selected analytical data from previous investigations. Appendix B contains a listing of containers, preservatives, packaging, and shipping requirements for soil and groundwater analytical samples.

1.2 BACKGROUND

Hill AFB is located 25 miles north of Salt Lake City, Utah, just east of Interstate 15 (Figure 1.1). Hill AFB was added to the National Priorities List (NPL) in July 1987. OU 1 is located in the northwestern corner of Hill AFB (Figure 1.1). This demonstration will focus on the plume in the area of OU 1 (Figure 1.2). The plume emanates from potential sources in eight sites, including Chemical Disposal Pits (CDPs) 1 and 2, Landfills (LFs) 3 and 4, Fire Training Areas (FTAs) 1 and 2, a Waste Phenol/Oil Pit (WPOP), and a Waste Oil Storage Tank (WOST) area. Locations of these areas are displayed in Figure 1.2. The following historical review of the sites was compiled during the performance of a remedial investigation (RI) (Montgomery Watson, 1995).

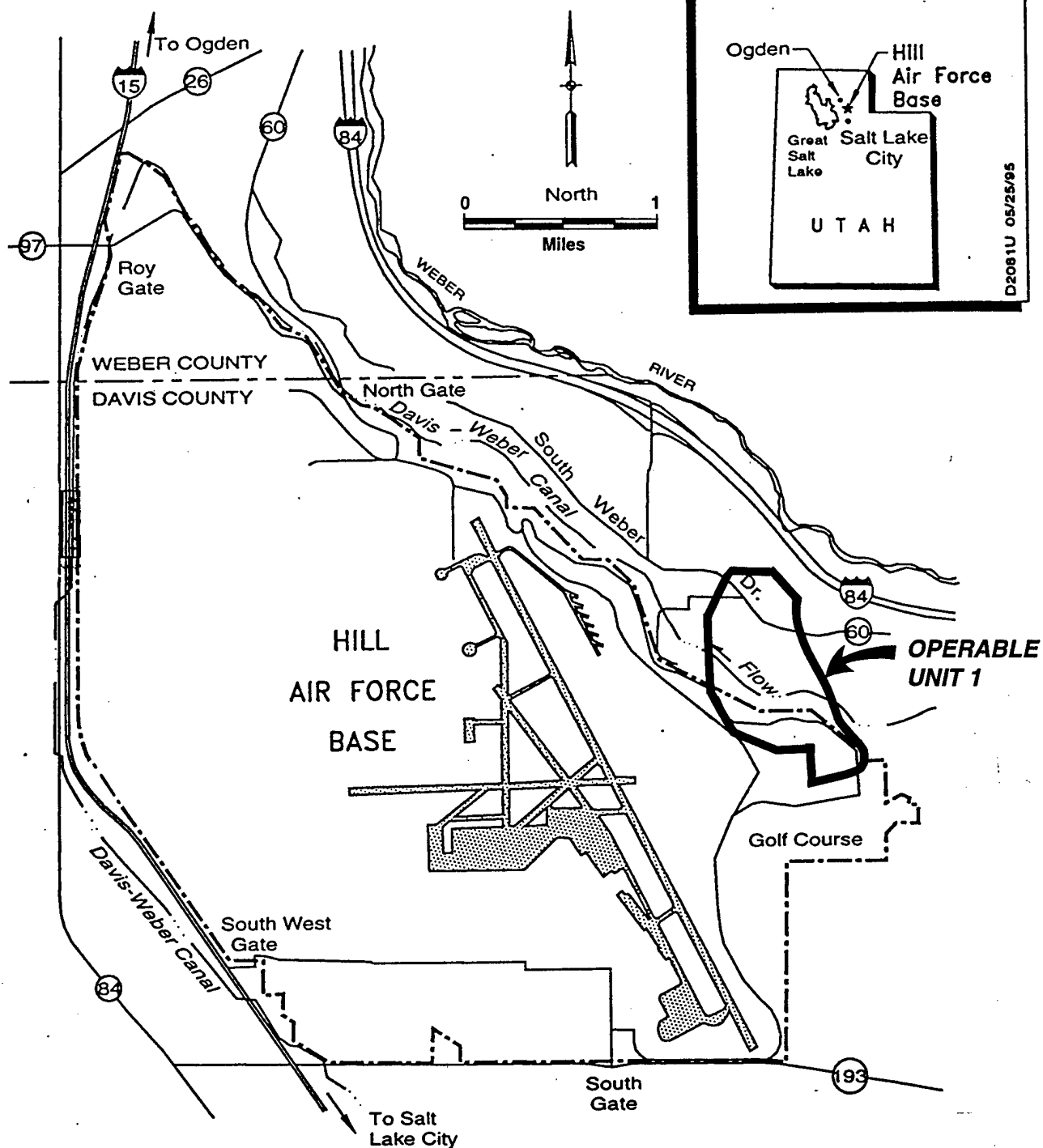


FIGURE 1.1

**LOCATION OF
HILL AFB AND OPERABLE UNIT 1**

Hill Air Force Base, Utah

**PARSONS
ENGINEERING SCIENCE, INC.**

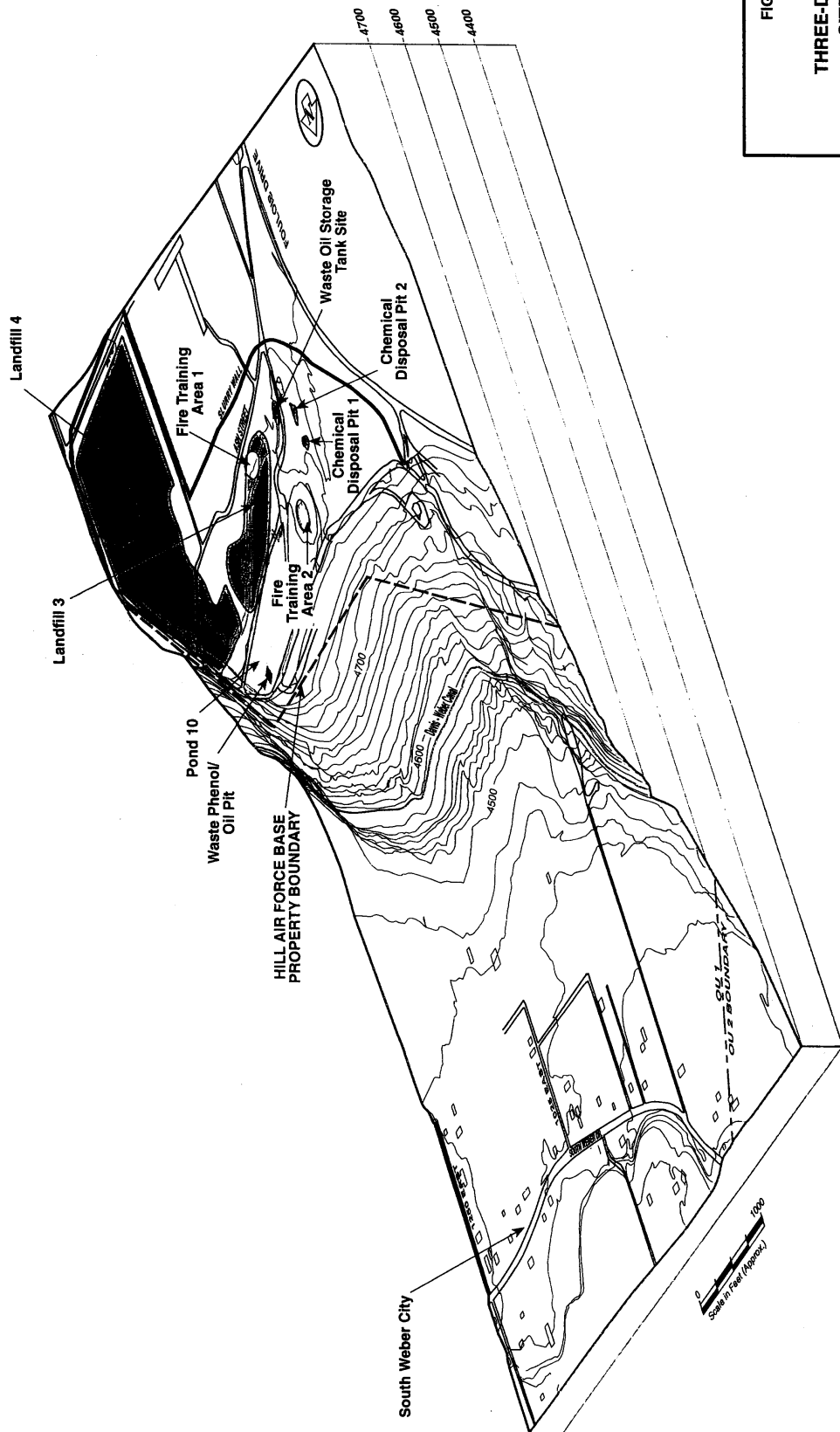


FIGURE 1.2

**THREE-DIMENSIONAL
SITE MAP OF
OPERABLE UNIT 1**

Hill Air Force Base, Utah

**PARSONS
ENGINEERING SCIENCE, INC.**

Note: Soil excavated from the Waste Phenol/Oil Pit was placed under the clay cap of Landfill 3.

Source: Montgomery Watson, 1995.

Construction of CDPs 1 and 2 began in 1939 and 1940, as gravel was excavated from these areas for use in roadway and runway construction. The pits were used for disposal of liquid industrial waste from 1952 through 1973. The wastes most frequently reported to be disposed of at CDPs 1 and 2 include waste oil, petroleum hydrocarbons, and spent solvents. In 1986 the CDPs were capped using silty sand with some bentonite.

LFs 3 and 4 also were constructed in 1939 and 1940 through the excavation of gravel for roadway and runway construction. Both liquid and solid wastes were disposed of in LF 3 from 1940 through 1967. Wastes disposed of at LF 3 included: solid refuse (construction debris); industrial wastewater treatment plant (IWTP) sludge, drying bed, and flocculation tank wastes; spent solvents; residues from solvent cleaning operations; and residues and filters from plating and cleaning operations. Waste was burned in LF 3 on a daily basis until disposal activities were moved to LF 4 in 1967. LF 4 was used as a sanitary landfill from 1967 to 1973, mostly receiving solid waste (scrap metal, construction debris, domestic refuse, industrial dumpster refuse) and small amounts of sulfuric acid, chromic acid, phenol, and methyl ethyl ketone (MEK). In 1985 LFs 3 and 4 were capped with a bentonite soil layer. Currently, a compass repair facility, a generator repair building, and a cannon test facility are located between LFs 3 and 4.

FTAs 1 and 2 were used as practice areas to extinguish simulated aircraft fires. FTA 1 was used from 1958 through 1973, when the activity was moved to FTA 2 and continued until January 1995. No evidence of controls for the containment of fuels or chemical retardants were found at FTA 1; exercises at FTA 2 were staged on a earthen pad surrounded by a berm. The primary type of waste associated with the FTAs is liquid hydrocarbon fuels that were burned during fire training exercises, but the waste fuels may have contained other products such as hydraulic fuels or solvents. Fire training activities utilizing the earthen pad at FTA 1 were discontinued in January of 1995. As of 1995, a smokehouse at FTA 2 was being used as the training area until a new training area is completed.

The WPOP was a brick-lined burn pit, used periodically to dispose of waste oil and phenol from approximately 1954 through 1965. In 1986, the WPOP was removed, along with associated soils, and disposed of in LF 3.

The WOST area consisted of four aboveground storage tanks located southeast of the CDPs and southwest of LF 3 (Figure 1.2). One tank was installed in 1965 to store fuel and crankcase oil. Other wastes stored in this tank included engine oil, JP-4 jet fuel, waste motor oil, and hydraulic fluid. The date of removal of this tank is not known. Three additional tanks were installed in 1981. It is believed these tanks contained wastes similar to the original tank. These tanks were removed in 1985.

Based on the historical information gathered by Montgomery Watson (1995), it is highly unlikely that explosives or unconventional munitions (chemical warfare agents or defoliants) were used or disposed of at CDPs 1 and 2, LFs 3 and 4, FTAs 1 and 2, the WPOP, or the WOST area.

As early as 1976, Hill AFB recognized that there were potential problems associated with the waste material disposal practices at OU 1 (Montgomery Watson, 1995). Early

investigations included Goodwin (1976) and CalScience Research, Inc. (CSR) (1981). The purpose of the investigation by Goodwin (1976) was to evaluate the contamination associated with LFs 3 and 4. The study ultimately included CDPs 1 and 2 and 40 acres of private property bordering the Davis-Weber Canal. During that investigation, soil boring were drilled, monitoring wells (U-001 through U-011) were installed, and soil, groundwater, drainline effluent, and surface water samples were collected and analyzed. A clay layer was identified approximately 30 feet below ground level (bgl). Organic and inorganic contaminants were found in the areas of the LFs and in seeps downgradient of LF 4. Light, nonaqueous-phase liquid (LNAPL) was detected on groundwater west of the CDPs and west of FTA 2. Frequent and uncontrolled spills at FTA 2 were documented.

The object of the CSR (1981) investigation was to examine the migration of LF 4 leachate to groundwater and springs on the escarpment north of LF 4. Evaluating groundwater elevation and flow direction, characterizing the soils underlying the southern portion of LF 4, and determining the mass balance of groundwater moving through LF 4 were included in this study. The investigation included drilling two soil borings, collecting surface soil and groundwater samples, installing two monitoring wells, and measuring water levels at the site monitoring wells. The study identified a clay layer underlying the study area approximately 30-35 feet bgl and detailed possible mechanisms for the generation and migration of leachate.

Beginning in 1982, field work at these sites was conducted as part of the Installation Restoration Program (IRP) effort. A Phase I Records Search was conducted to identify past and present waste disposal practices that lead to contamination at Hill AFB, and to assess the potential off-Base migration of contaminants (ES, 1982). The search included interviews with personnel aware of past and present disposal practices and record searches on the associated facilities. Results of this study consist of a history of waste disposal practices at Hill AFB, including the areas of CDPs 1 and 2, LFs 3 and 4, FTAs 1 and 2, WPOP, and WOST area. The United States Air Force (USAF) Hazard Assessment Rating Methodology (HARM) was used to evaluate the potential for environmental contamination based on site characteristics, waste material characteristics, and waste management practices.

Additional site assessments further examined the contamination at OU 1. After installing additional monitoring wells (U1-041A - U1-048), obtaining groundwater samples, and performing geophysical surveys at CDPs 1 and 2, LF 3, and the site golf course (located on 160 acres near the southeastern portion of OU 1), volatile organic compounds (VOCs) were identified in the groundwater in the vicinity of CDPs 1 and 2 and LF 3 [Radian Corporation (Radian) *et al.*, 1984]. The study detected a continuous clay layer beneath the CDPs at depths of 30 to 50 feet bgl and clay lenses underlying LF 3. Radian *et al.* (1984) concluded that groundwater flowed from the CDPs to the northwest with a secondary northern component.

A subsequent investigation [Radian and Science Applications International Corporation (SAIC), 1988], included geophysical surveys (Weston Geophysical, 1986), soil borings, installation of monitoring wells (U1-037 - U1-040, U1-049 - O1-061, and U1-064 - U1-087), collecting soil, surface water, and groundwater samples, slug tests,

and groundwater modeling. The areas studied were CDPs 1 and 2, LFs 3 and 4, FTA 1, and the golf course. VOCs were identified in groundwater and surface water near and downgradient from LFs 3 and 4 and CDPs 1 and 2. The presence of metals (arsenic, barium, iron, chromium, and manganese) at concentrations exceeding the Safe Drinking Water Act (SDWA) maximum concentration levels (MCLs) was detected in groundwater samples from CDPs 1 and 2 and LFs 3 and 4. The study also concluded that by increasing the amount of aquifer recharge, irrigation water from the golf course had the potential of increasing the migration rate of contaminants originating at OU 1.

A Phase I RI was conducted by James M. Montgomery, Consulting Engineers, Inc. (JMM) in 1990 and 1991 (JMM, 1991). The purpose of the Phase I RI was to assess the risk to human health and the environment resulting from disposal practices at LFs 3 and 4, CDPs 1 and 2, and FTAs 1 and 2. Locations of these areas are indicated in Figure 1.2. During Phase I of the RI the following activities were conducted:

- A water rights survey located nine sources of potable water, including the City of South Weber Municipal Well 6-210, six springs, and two seeps.
- A passive soil gas survey of 200 locations in the Weber River Valley and adjacent hillside was conducted to identify possible source areas of contaminants, and to aid in the selection of monitoring well locations.
- Sixteen soil borings (U1-727 through U1-742) were drilled on-Base and sampled to evaluate soil contamination in the proximity of CDPs 1 and 2 and LFs 3 and 4. Four 2-foot intervals of soil were collected from each boring and submitted for analysis of soil-pore fluid. Eight of the soil borings were completed as monitoring wells.
- Three deep soil borings were drilled to provide continuous lithologies of underlying sediments. Two of these borings were completed as monitoring wells (U1-088 and U1-090).
- Eight shallow monitoring wells (U1-091 and U1-093A through U1-099) were installed off-Base to evaluate the presence of contaminants in groundwater.
- Groundwater from the monitoring wells was collected and analyzed for various compounds, including anions, cations, metals, and VOCs.

Phase II RI work was initiated by JMM in 1992. During this RI, JMM collected additional information to better characterize the contamination associated with the CDPs, LFs, and FTAs, WOST, and WPOP, as well as to determine the lateral extent and thickness of LNAPL associated with these areas. Cone penetrometer tests (CPTs) were conducted, soil borings were advanced, and monitoring wells were installed. LNAPL sampling was conducted to determine the constituents of the LNAPL. Results of this work are summarized in a comprehensive RI report (Montgomery Watson, 1995).

1.3 SITE REMEDIATION ACTIVITY

In 1984 a Cease and Desist Order was issued by the Utah Water Pollution Control Board (currently the Division of Water Quality) for leachate discharge below LF 4. Hill AFB implemented several interim remedial actions to mitigate the migration of contaminants originating from OU 1. The following remedial options were executed:

- LFs 3 and 4 were capped with bentonite soil layers in 1985 to reduce infiltration and potential contaminant migration.
- A retention pond (Pond 10 in Figure 1.2) was constructed to collect surface runoff from the LF caps.
- In 1985 a slurry wall was installed around the southern (upgradient) perimeter of OU 1 to limit groundwater recharge from upgradient sources (Figure 1.2).
- A groundwater extraction and treatment system with infiltration gallery was installed downgradient from LFs 3 and 4 (near CDPs 1 and 2) to collect contaminated groundwater before it migrated off-Base.

The caps for LFs 3 and 4 were designed to consist of 2 feet of compacted bentonite overlain by approximately 3 feet of silty soil; however during a subsequent investigation, results indicated that the bentonite cap was 2 to 2.5 inches thick and covered by 15.5 to 20 inches of soil. Laboratory results also indicated that the cap of LF 4 did not meet its specified permeability requirement of 10^{-7} centimeters per second (cm/sec) or less (Dames & Moore, 1986).

In 1984, the slurry wall was constructed to prevent groundwater flow from the south and southeast to recharge the OU 1 source areas. The 5,200-foot long slurry wall was designed to extend 47 to 52 feet bgl and to be keyed into the underlying clay layer. According to Dames & Moore (1985a and 1985b), the slurry wall extended only 35.5 to 40.5 feet bgl and did not completely tie into the clay layer, allowing potential horizontal seepage of groundwater into the OU 1 source area, and failed to meet permeability specifications. In an additional study, Dames & Moore (1985c) indicated that redirection of the groundwater by the slurry wall could adversely affect slope stability.

The groundwater recovery and treatment system consists of seven groundwater extraction wells: two near the CDPs, four on the eastern boundary of OU 1, and one west of LF 4. A 1,500-foot-long groundwater extraction trench extends east from FTA 2 to the perimeter road. The system also includes three pumping stations that collect water from hillside springs. The collected groundwater is transported to a 250,000-gallon holding tank at the on-Base IWTP via a 3-mile-long, high-density polyethylene (HDPE) underground pipeline.

Previous monitoring programs (i.e., chemical analysis of groundwater samples and collecting groundwater elevation measurements) have been instituted by Hill AFB. Off-Base seeps have been monitored since 1976, while monthly groundwater elevation measurements have been collected since 1985. Analysis of contaminants began in 1981,

and since 1988, the extraction wells and seeps have been sampled and analyzed for contaminants.

Various remedial actions are being planned for sites in the OU 1 area. Presently the chemical disposal trench in the CDP area is undergoing eight separate treatability studies. A bioventing system is being designed for use in the FTA 2 area, and a soil vapor extraction system is under consideration for CDP 1.

SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Existing site-specific data were reviewed and used to develop preliminary conceptual models for groundwater flow and contaminant transport at OU 1. Section 2.1 presents a synopsis of available site characterization data. Section 2.2 presents the preliminary conceptual groundwater flow and contaminant transport models that were developed based on these data. The conceptual models guided the development of sampling locations and analytical data requirements needed to support the modeling efforts and to evaluate potential remediation technologies, including RNA. Sampling locations and analytical data requirements are discussed in Section 3.

2.1 DATA REVIEW

The following sections are based upon review of data from the following sources:

- Montgomery Watson (1995).
- JMM (1991).

2.1.1 Topography, Surface Hydrology, and Climate

Hill AFB is located in northern Utah, approximately 25 miles north of Salt Lake City and 5 miles south of Ogden. The Base contains 6,666 acres in Davis and Weber Counties. The western boundary of the Base is near Interstate 15, and the southern boundary is near State Route 193 (Figure 1.1). The northern and northeastern perimeters of the Base are bounded by the Davis-Weber Canal, a privately owned irrigation canal. The Wasatch Mountain Range is about 4 miles to the east, and the Great Salt Lake is about 6 miles to the west. The Base is located within the Bonneville Basin subsection of the Great Basin section of the Basin and Range physiographic province.

Hill AFB is located on a plateau that rises approximately 300 feet above the Weber River Valley on the east and approximately 50 to 100 feet above Sunset and Clinton on the west. Except for areas dissected by erosion, most of Hill AFB is relatively level, ranging in altitude between approximately 4,550 and 4,800 feet above mean sea level (msl). The immediate area of the CDPs, LFs, FTAs, WPOP, and WOST area is relatively flat, sloping downward gradually at the northern and eastern ends. The elevation of this area is approximately 4,800 feet msl. The topography to the north and east of this area slopes steeply downward (Figure 1.2).

The climate of Hill AFB is semi-arid. Mean annual precipitation is just over 18 inches, and annual evaporation is approximately 45 inches (Feth *et al.*, 1966). At Ogden, just north of Hill AFB, the average temperature is 50.5 degrees Fahrenheit (°F); mean monthly temperatures range from 25°F in January to 75°F in July. Winds average about 5 knots and are generally out of the south and east-southeast, although winds from the north and northwest are common.

2.1.2 Overview of Geology and Hydrogeology

2.1.2.1 Regional Geology and Hydrogeology

The geologic formations exposed at the surface in the vicinity of Hill AFB vary from Precambrian-age crystalline bedrock at the western margin of the Wasatch Mountain Range to Pleistocene unconsolidated deposits forming benches, plateaus, and lowlands west of the Wasatch Front (Figures 2.1 and 2.2). The plateau upon which Hill AFB is located is an erosional remnant of a fan-delta complex that formed as sediments were transported from the Wasatch front into Pleistocene Lake Bonneville. Coarse-grained fan-delta deposits of the (most recent) Provo stage of Lake Bonneville are exposed at the surface within the boundaries of the Base. The fan-delta has been dissected along the northeastern perimeter of the Base by the Weber River, creating a steep terrace. Older Alpine stage sediments of Lake Bonneville generally underlie the Provo deposits, and the silts, sands, and clays of a lower Alpine unit (Qac on Figure 2.2) are exposed on the steep hillsides northeast of the Base. Although older than the Provo stage sediments, some of the upper Alpine stage units were deposited at higher altitudes than Provo stage sediments because the lake level was higher during Alpine time. These upper coarse-grained Alpine units (Qag and Qas on Figure 2.2) crop out at the far eastern portion of the Base and form remnant hilltops.

Perched, shallow water-bearing zones that collectively form a shallow unconfined aquifer system are present in the unconsolidated Provo and Alpine stage Lake Bonneville deposits. In the OU 1 area, groundwater flow in the shallow groundwater system is generally to the northwest and northeast. Elsewhere on the base, groundwater flow in the shallow groundwater system varies, and the flow direction and magnitude may be locally controlled by topography or subsurface features.

In addition to the formations exposed at the surface, 2,000 to 3,000 feet of pre-Lake Bonneville sediments are present in a north- to south-trending graben underlying the area of Hill AFB (Feth *et al.*, 1966). This basin fill consists of thick sequences of interbedded coarse alluvium and lacustrine clays. The coarse alluvial units are successively older (and deeper) lobes and layers of the fan-delta complex, and they function as artesian aquifers. Two artesian aquifers that supply water to Hill AFB and the surrounding communities are present beneath the Base: the shallower, less transmissive Sunset Aquifer and the deeper, highly transmissive Delta Aquifer. The general pattern of groundwater flow in the deeper aquifers is east to west, from the recharge areas toward the Great Salt Lake. The potentiometric surfaces in the deep aquifers beneath the Base are relatively flat. However, because of high pumpage, local perturbations of the potentiometric surfaces are evident and the potentiometric surfaces

Symbol	System	Series	Formation and Lithology	Thickness (in Feet)
Qa Qg Qs Qc	Quaternary	Recent	Alluvium: Permeable river sand and gravel; includes mudflow deposits near mountains which are impermeable locally. Gravel: Permeable floodplain sand and gravel. Sand: Permeable fine sands underlying lowlands. Clay: Impermeable plastic to non-plastic clay overlying artesian aquifer.	200 10-20 35+
UNCONFORMITY				
Qpg Qpgs Qps	Quaternary	Pleistocene	(Lake Bonneville Group): Provo Formation: gravel, permeable; gravel and sand, permeable; sand, permeable	5-20 10-50 10-20
Qba			Bonneville and Alpine Formation: sand and gravel over bedrock, very permeable	5-50
Qag Qas Qac			Alpine Formation: gravel, permeable; sand, permeable; clay silt, fine sand, usually impermeable;	<25 100 200
Q			Unconsolidated basin-fill deposits	>1000
UNCONFORMITY				
Cl	Cambrian	Middle to Late (?)	Limestone: Silty with interbedded shale and dolomite. Permeable.	1375(±)
Cr		Lower to Middle (?)	Tintic Quartzite: massive, cross-bedded, pebbly. Permeable where fractured.	500-700
ANGULAR UNCONFORMITY				
Pcf		Precambrian	Farmington Canyon Complex: metasedimentary and metavolcanic rocks. Permeable where jointed or fractured.	10,000

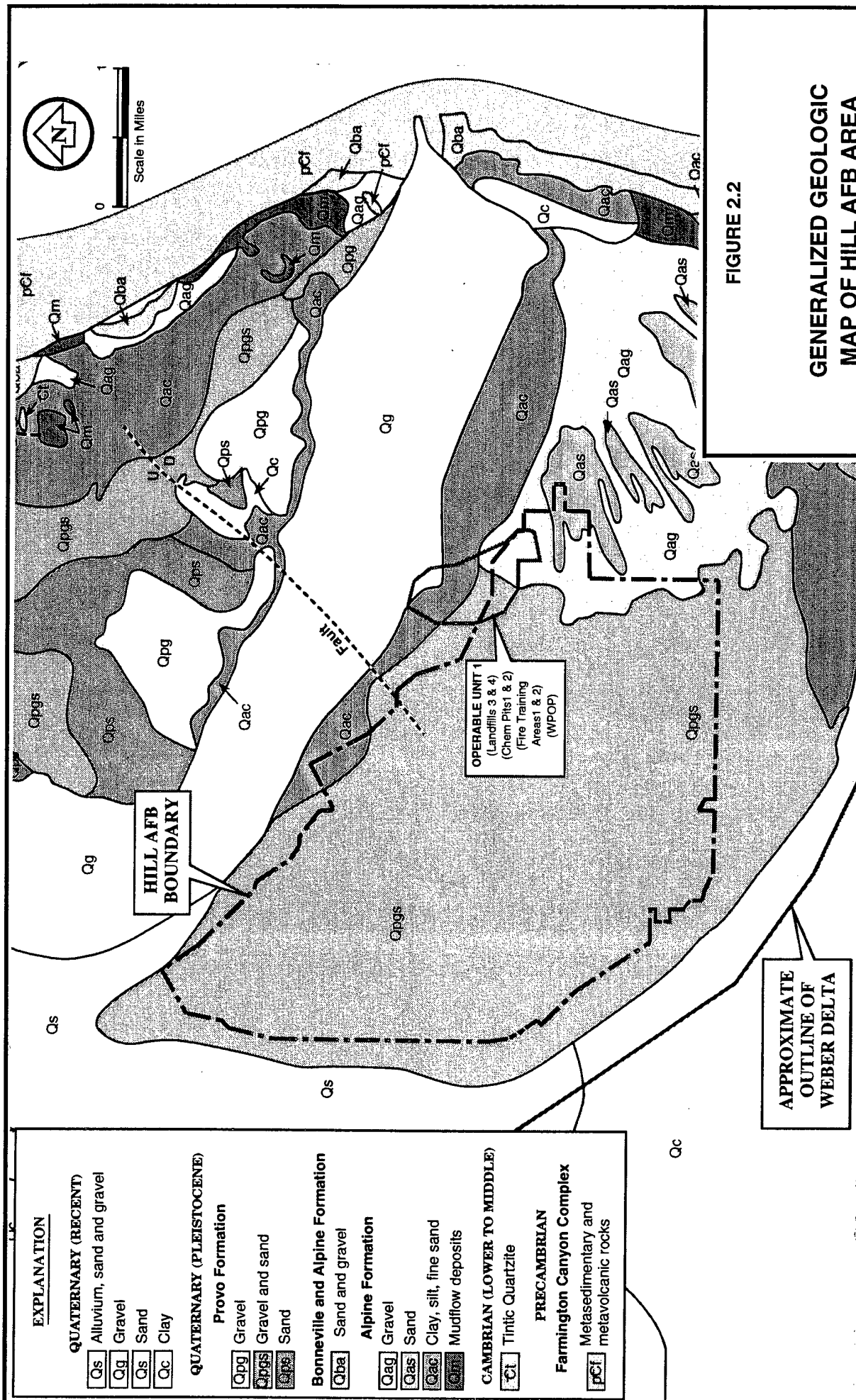
SOURCE: Modified from Feth et al. (1966)

FIGURE 2.1

GENERALIZED STRATIGRAPHY OF THE HILL AFB AREA

Hill Air Force Base, Utah

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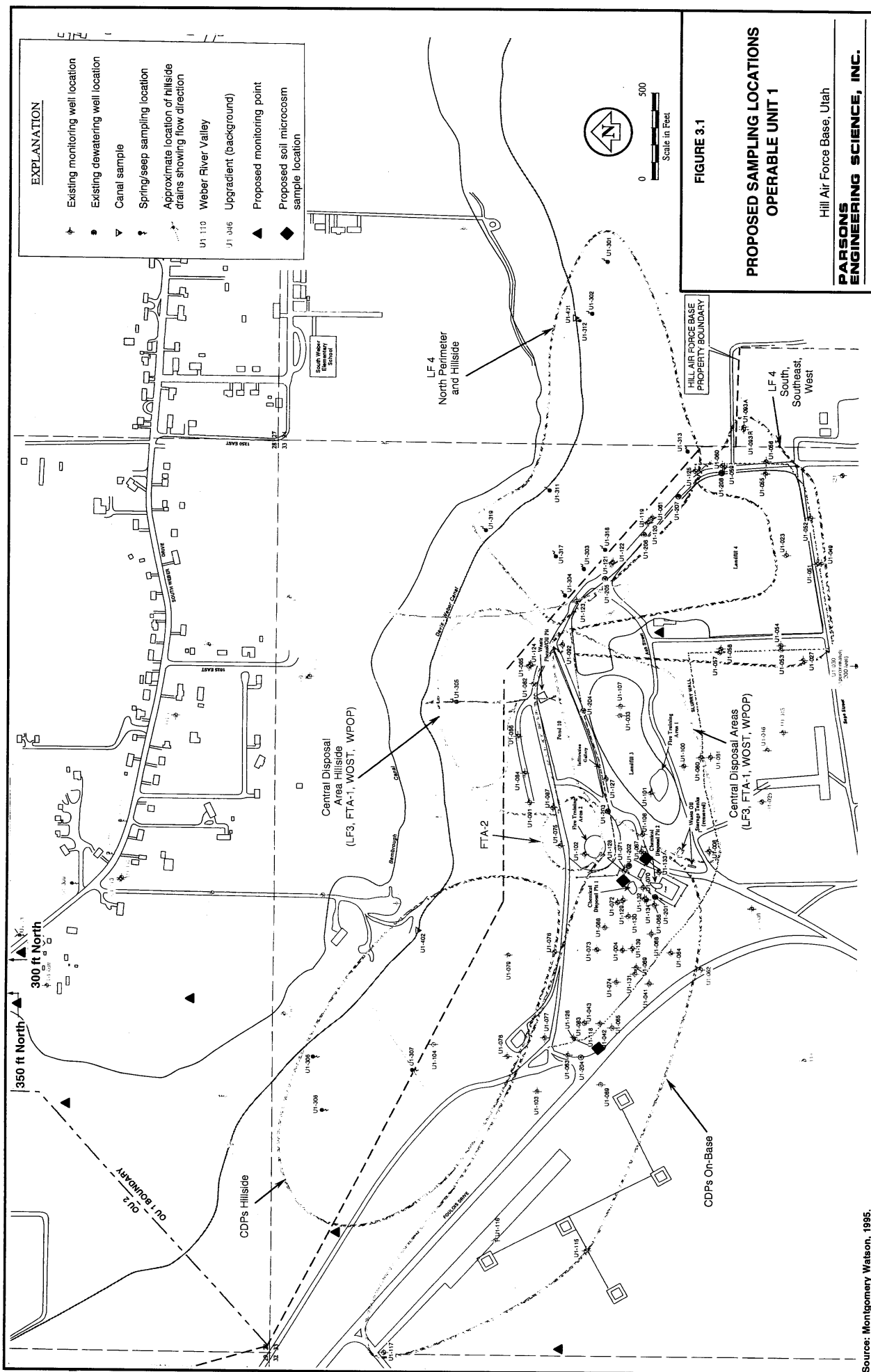


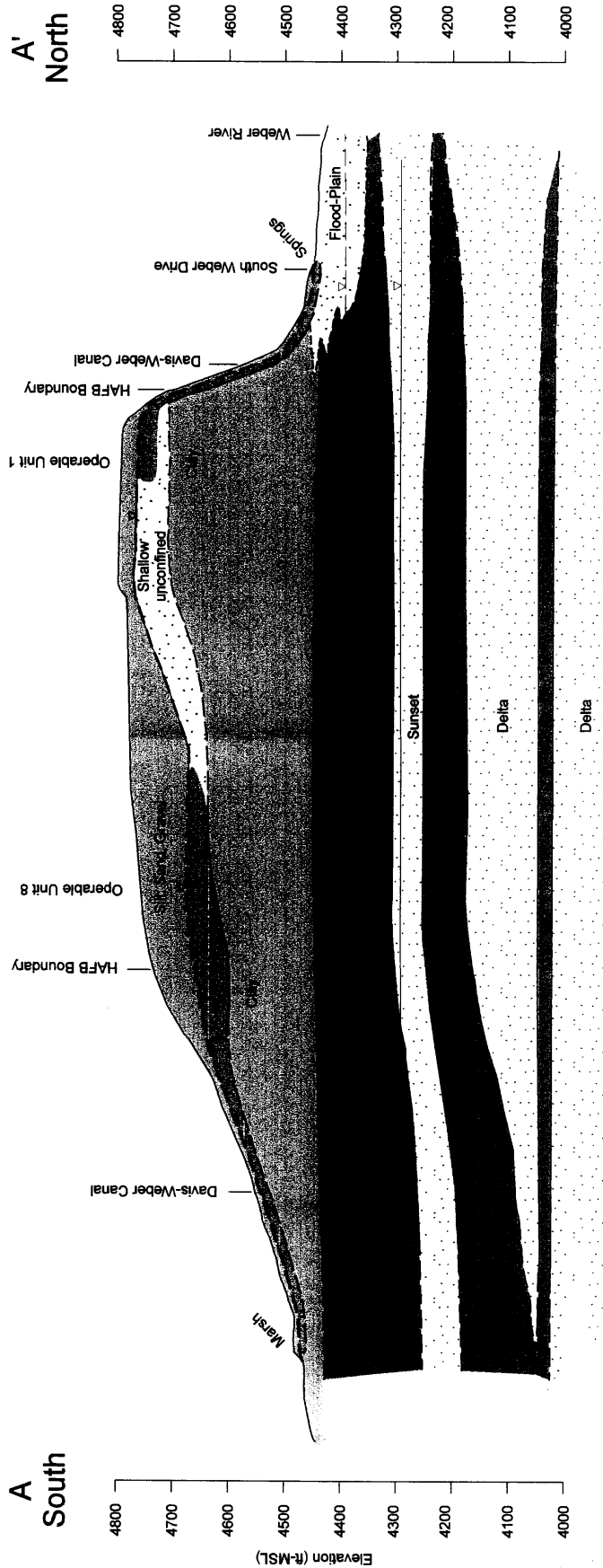
have been lowered substantially. Cross-sections showing the relationship of the hydrostratigraphic units beneath the base and the potentiometric surfaces of the aquifers are shown in Figures 2.3 and 2.4; lines of cross-section are shown in Figure 2.5. The hydrostratigraphic cross-sections have been compiled from drillers' logs of deep production wells, published technical reports, and Hill AFB RI results.

With respect to regional groundwater flow patterns, vertical flow is downward in recharge areas near the mountain front and upward in discharge areas to the west of the Base, near the Great Salt Lake. This general pattern of recharge and discharge may be locally affected by groundwater pumping, but should be relatively unaffected at the regional scale. On the basis of the potentiometric surfaces of the aquifers beneath the Base, downward components of flow from the shallow unconfined aquifer to the deeper Sunset and Delta aquifers are inferred. However, the downward movement of groundwater through the clay layers and confining units between the aquifers depends on the degree of hydraulic connection among the aquifers, which in turn depends on the thickness and hydraulic properties of the clay layers separating the aquifers. Drillers' logs indicate that the confining units in the area of the Base are primarily tight blue-gray clay. The extensive clays separating the aquifers appear to limit the hydraulic connection among the aquifers, and thus, the amount of recharge and vertical leakage. The deep aquifer system becomes unconfined and less differentiated near the mountain front and the mouth of Weber Canyon. This eastward unconfined extension of the deep aquifer system is the main source of recharge to the deep aquifers. Recharge to the deeper aquifers primarily occurs near the mountain front by direct infiltration into the more permeable Lake Bonneville deposits and by seepage losses from the Weber River. The Sunset and Delta aquifers are more differentiated near OU 4, and the Weber River drainage is underlain by a thicker sequence of clay [see cross-section B-B' (Figure 2.4)]. Therefore, the river does not appear to be a primary source of groundwater influx to the deeper aquifers in the area downgradient of OU 4.

High-yield production wells at Hill AFB are screened in one or both coarse-grained water-bearing units of the Delta Aquifer starting at about the 4,200-foot elevation. Logs for city wells to the west and south of Hill AFB indicate that the upper water-bearing unit or lobe of the Delta Aquifer fan complex thins and eventually terminates in these directions. Therefore, this upper lobe is unique to the Hill AFB area. The lower water-bearing unit of the Delta Aquifer is tapped elsewhere outside of the Base. The shallower, lower yield Sunset Aquifer is more differentiated from the Delta Aquifer in the areas west and southwest of the Base and is used for water supply in these areas, though less frequently than the Delta Aquifer.

The areal extent and morphology of the dissolved CAH groundwater plumes at Hill AFB OUs 1, 2, 4, 5, 6, and 8 are shown in Figure 2.5. The relationships between the geology, topography, hydrostratigraphic units, and selected dissolved CAH plumes beneath Hill AFB are shown on hydrostratigraphic cross-sections A-A' and B-B' (Figures 2.3 and 2.4). As shown in the figures, the plume morphologies and extents are geologically, topographically, and hydrologically controlled, and they all terminate at approximately the same elevation (4,440 to 4,450 feet msl). In the upper part of the delta, the interaction of Lake Bonneville and the delta resulted in a complex system of





Legend:



Aquifers (Shallow Unconfined, Flood-plain, Sunset, Delta)



Groundwater Contaminant Plumes



Lake Bonneville Group (Provo and Alpine Stage)



Confining Units (primarily clay)

--- -- -- Shallow Unconfined Aquifer static water level

--- -- -- Sunset Aquifer potentiometric surface (JMM, 1989)

--- -- -- Delta Aquifer potentiometric surface - 1985 (Clark and others, 1990)

--- -- -- Contact (dashed where inferred)

0 2000
Horizontal Scale in Feet
Vertical Exaggeration = 10x

FIGURE 2.3

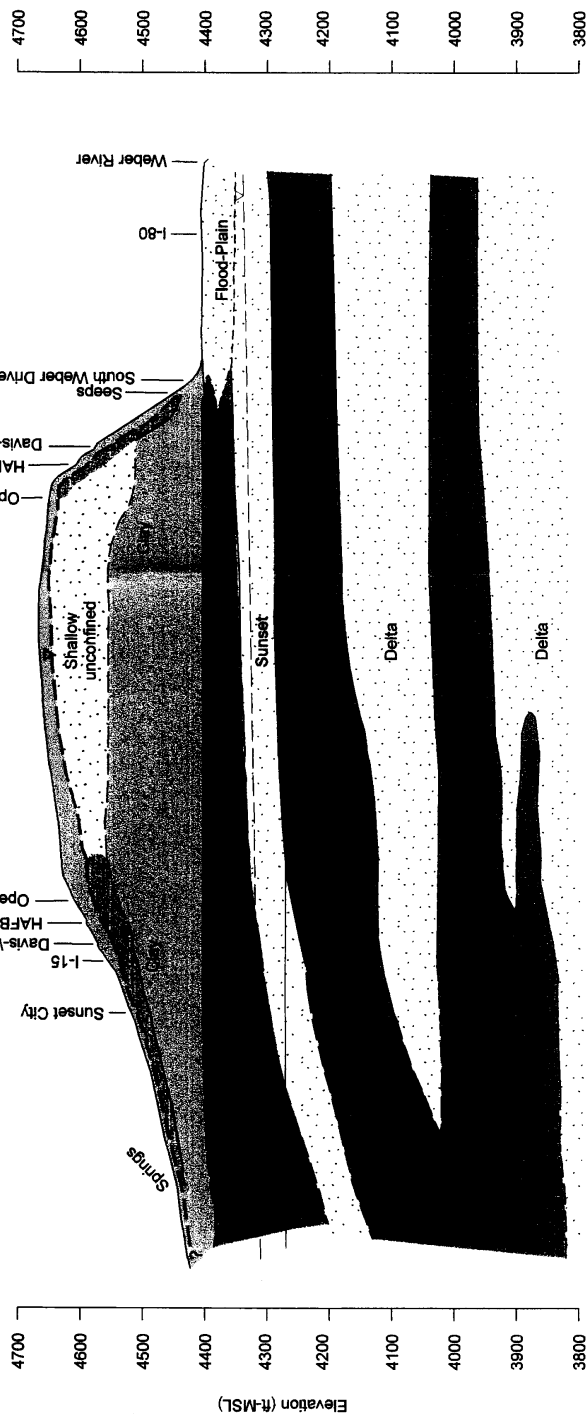
**HYDROSTRATIGRAPHIC
CROSS-SECTION A-A'**

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B
West

B'
East



Legend:



Note: Upward hydraulic gradients are present in the Flood-plain Aquifer at OUA (USGS, 1992)

Delta Aquifer potentiometric surface - 1985 (Clark and others, 1990)

Lake Bonneville Group (Provo and Alpine Stage)

Confining Units (primarily clay)

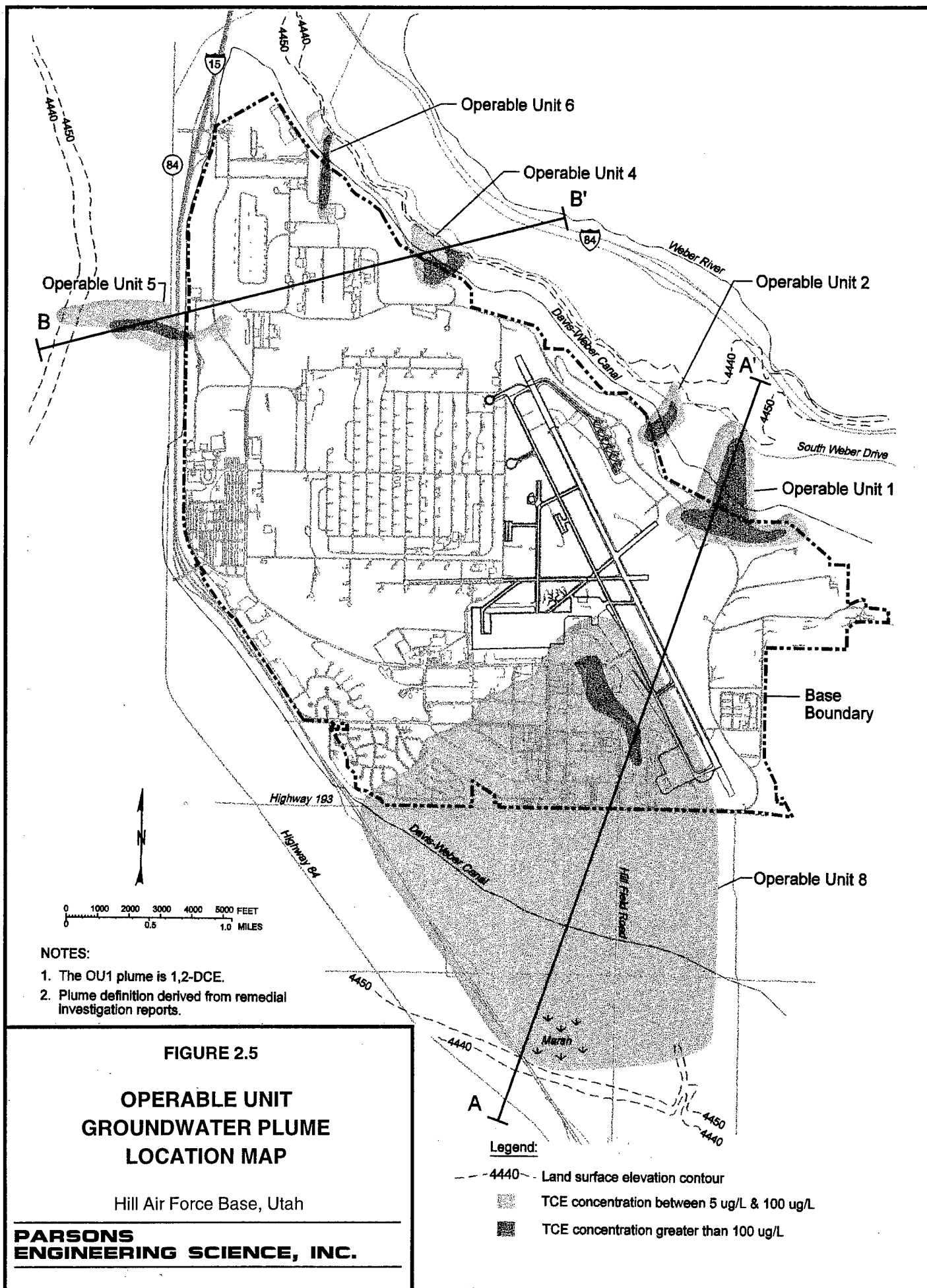
0 2000
Horizontal Scale in Feet
Vertical Exaggeration = 10x

FIGURE 2.4

HYDROSTRATIGRAPHIC CROSS-SECTION B-B'

Hill Air Force Base, Utah

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interfingering lenticular strata where the more coarse grained units likely act as preferential pathways for contaminant transport. For instance, the groundwater plume at OU 6 is constrained to a long, narrow trough of coarser sediment bounded on all sides by less permeable fine-grained sediments (Figure 2.5). Conversely, the plume at OU 5 is less constrained laterally and is thus wider. All plumes are constrained vertically with depth by the progressively fine-grained units within the Lake Bonneville Group deposits; with the base of the shallow groundwater system (shallow unconfined aquifer) defined by an irregular contact surface with low permeability clay (Figures 2.3 and 2.4).

As noted, relatively coarse-grained units may control plume migration in areas with complex and variable stratigraphy. Contaminants likely flow through zones with higher hydraulic conductivities relative to surrounding sediments. Given that the shallow groundwater system beneath Hill AFB consists of highly heterogeneous alluvial sediments deposited in a fan-delta complex, the potential for preferential and rapid migration in coarse-grained units must be considered when evaluating groundwater contaminant migration. For example, at OU 5, groundwater velocity measurements have been collected using a borehole flowmeter (Wheeler, 1996). These data suggest that within a single well, velocities may vary by a factor as great as 10, and that across the site, velocities may differ a factor of nearly 70 (i.e., nearly two orders of magnitude). This has also been observed at UST Site 870 at Hill AFB (JMM, 1993; Parsons ES, 1995). At that site, slug and pumping tests were conducted in wells screened across different stratigraphic intervals (e.g., some fine grained and some coarse). Results of these tests varied over two orders of magnitude, suggesting that for equivalent gradients and porosities, groundwater velocities at Site 870 could vary by two orders of magnitude. In general, at Site 870, wells with higher measured conductivities were screened mostly across sandy intervals, while wells with lower measured conductivities were screened mostly across finer-grained intervals (containing more silt and clay). Due to this heterogeneity, use of an average conductivity for transport modeling may not be appropriate. The distribution of hydraulic conductivity at OU 1 may therefore be further defined using borehole flowmeter testing, as described in Section 3.5.2.

Contaminants at the OUs have migrated vertically through the coarse near-surface sediments to the shallow perched water table, and have then migrated laterally off-Base. The plumes terminate in the vicinity of springs, seeps, or marshy areas. Discharge also occurs at other upslope spring/seep locations at most of the OUs. The spring/seep line of discharge at the downgradient leading edges of the plumes may result from the several factors such as structural contacts with clay units, topographic low spots, and upward hydraulic gradients in the lowland areas. Upward hydraulic gradients were confirmed in the Weber River flood-plain silts, sands, and gravels at the downgradient reaches of the OU 4 plume, as shown on Figure 2.4 [US Geological Survey (USGS), 1992]. Upward hydraulic gradients in shallow groundwater may be present at the other OUs, and this as well as other factors (i.e., discharge, evapotranspiration, dilution, dispersion, biodegradation, etc.) appear to be controlling the downgradient extent of the plumes and may be the reason that the plumes all terminate at approximately the same elevation.

Natural attenuation mechanisms appear to have stabilized the leading edge of the plumes at their current locations and elevations. This conclusion is supported by chemical data obtained from the off-base downgradient springs and seeps. Since 1986, many of the springs and seeps on the downgradient edges of the plumes have been sampled and analyzed for CAHs, with no apparent increasing trend. For example, the spring below Petersons Pond at OU 2 contained TCE at a concentration of 44 µg/L when first sampled in 1986. A TCE maximum concentration of 373 µg/L was detected in May of 1987, and, concentrations of TCE have diminished since 1987. Seasonal variability may be more significant than long term trends; concentrations of CAHs in this spring and downgradient springs at the other OUs are generally higher in the late spring and summer months. At OU 8, water in off-base downgradient field drains has contained CAHs since the drains were first sampled in the 1980s. During the period of 1986 to 1994, concentrations of TCE ranging from 16 µg/L to 89 µg/L have been detected in a field drain behind the Jay Harris residence, which is located south of the Davis-Weber Canal. Over that time, there was no apparent increase in TCE concentrations. Approximately 1,500 feet further downgradient, TCE was detected at concentrations ranging from 11 µg/L to 21 µg/L in water collected from a manhole at the Reed Robins residence. This analytical data is for 1987 only. This location corresponds to the furthest downgradient detection of CAHs at OU 8. A marshy area (Figure 2.4) is located just south of this sampling location and appears to be a point of shallow groundwater discharge. At OU 5, relatively low concentrations of TCE were detected in two shallow domestic wells near 700 West in Sunset as early as 1987. Fred Chicado's well contained TCE at a concentration of 3.4 µg/L in 1987. TCE concentrations ranging from 6.6 µg/L to 7.5 µg/L were detected in Omer's well between 1989 and 1990. Martin Spring contained TCE concentrations ranging from 4.4 µg/L to 5.8 µg/L between 1989 and 1990. A maximum 1,2-DCE concentration of 8.9 µg/L also was detected. The presence of relatively stable concentrations of CAHs in spring water, field drains, and shallow groundwater far downgradient of the source areas since as early as 1986 suggests that the plumes are stable and are no longer increasing in size.

2.1.2.2 OU 1 Geology and Hydrogeology

The hydrogeologic features of OU 1 and nearby, hydraulically downgradient areas are defined by a combination of drilling and continuous logging at a total of 57 locations on-Base and 8 locations in South Weber, and cone penetrometer testing at 16 locations on-Base. These locations are shown on Figure 2.6. Depth to groundwater, groundwater flow, and hydraulic parameters have been defined from the collection of water-level measurements at most site wells and slug tests at 37 monitoring wells.

The subsurface features in the vicinity of the OU 1 and downgradient areas are consistent with the regional setting of the Provo Formation, consisting of fluvial-deltaic deposits of interbedded clay, silt, sand, and gravel. In general, deposits in the OU 1 area show a fining-downward trend. These deposits have been grouped into two main geologic units present in the following descending order (Montgomery Watson, 1995):

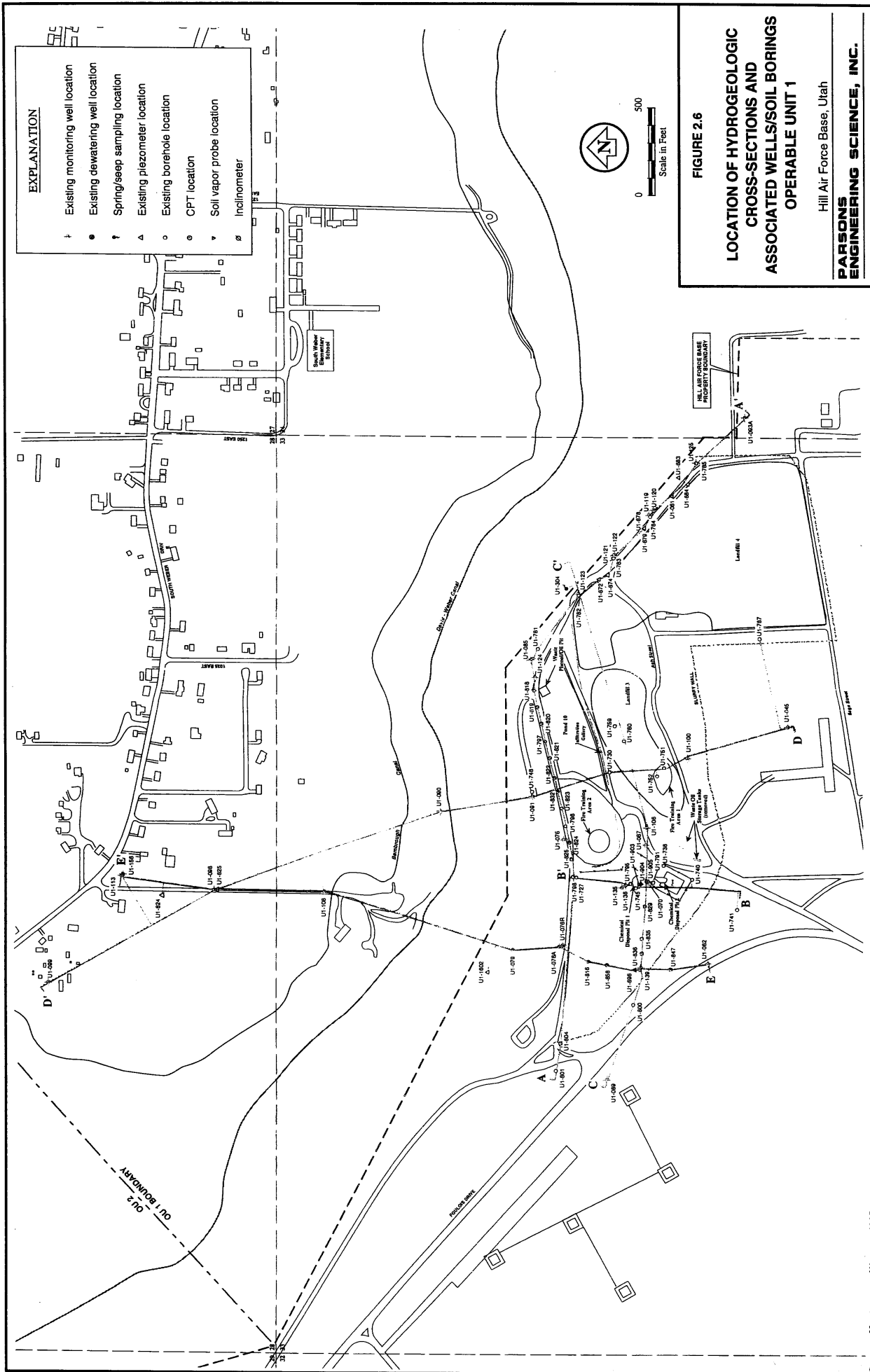


FIGURE 2.6

LOCATION OF HYDROGEOLOGIC CROSS-SECTIONS AND ASSOCIATED WELLS/SOIL BORINGS OPERABLE UNIT 1

Hill Air Force Base, Utah

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- Upper Sand and Gravel Unit - consisting of fine to coarse, clean to silty sands interbedded with gravel. The unit ranges in thickness from 0 to 62 feet and has an average thickness of approximately 30 feet. The saturated thickness ranges from 0 to 10 feet with an average of 3 feet.
- Silty Clay Unit - consists primarily of silty clay interbedded with fat clays and silts containing thin stringers of very fine sand (0 to 10 inches thick). This unit is approximately 200 feet thick.

The gravelly sand and silty sand unit is the principal sediment making up the shallow aquifer underlying the site. A surficial cap, 2 to 5 feet thick, of silty sand with occasional bentonite intervals is found over a large portion of OU 1. Four hydrogeologic cross-sections illustrating the subsurface stratigraphy and the relationship of the on-Base and off-Base areas, are shown in Figures 2.7 through 2.11. The locations of these sections are shown on Figure 2.6. Sections A-A' and C-C' provide a detailed east-to-west view of the stratigraphy and water levels of OU 1, with section C-C' running through the center of the CAH plume. Sections B-B', D-D', and E-E' show north-to-south sections nearly parallel to the direction of groundwater flow.

As shown on cross-sections B-B', D-D', and E-E', the surface topography, subsurface strata, and water table gradually slope to the north from the on-Base OU 1 area. There is approximately 300 feet of relief between the top of the escarpment at OU 1 and the Weber River Valley to the north (Figure 1.2). On-base in OU 1, the shallow sand and silt water-bearing zone is roughly 25 feet thick and is subtended by a silt/clay layer, which may constrain the vertical extent of contamination beneath the plume. The stratigraphic data downgradient (north) of the on-Base OU 1 area in the Weber River Valley show near-surface silt and sand layers with a depth to groundwater of approximately 5 feet bgl.

The water table in the shallow water-bearing zone in June 1994 is illustrated in Figure 2.12. Groundwater is 15 to 30 feet bgl in the on-Base OU 1 area, and emerges at the surface in the form of seeps and springs in the northern and western portions of the OU 1 on-Base area (Figure 2.13). Groundwater flow was north to northwest on-Base and to the north in the off-Base area. Across the OU 1 area, the saturated thickness of the shallow aquifer ranges from 0 to 10 feet.

On the basis of the hydrogeological cross-sections (Figures 2.7 through 2.11), there appear to be no lateral hydrogeological constraints on plume migration. However, the silt/clay layer(s) beneath the plume may effectively impede the downward migration of contaminants to deeper water-bearing zones.

A water rights search was conducted by Montgomery Watson (1995) to evaluate the use of groundwater from the shallow aquifer by residents in the South Weber area. The data collected indicates that all residences, schools, and businesses in South Weber area receive potable water from the municipal water system, and that no residents of the South Weber area are obtaining shallow aquifer groundwater for potable use. In addition, Hill AFB is aware of all springs and wells that have associated water rights,

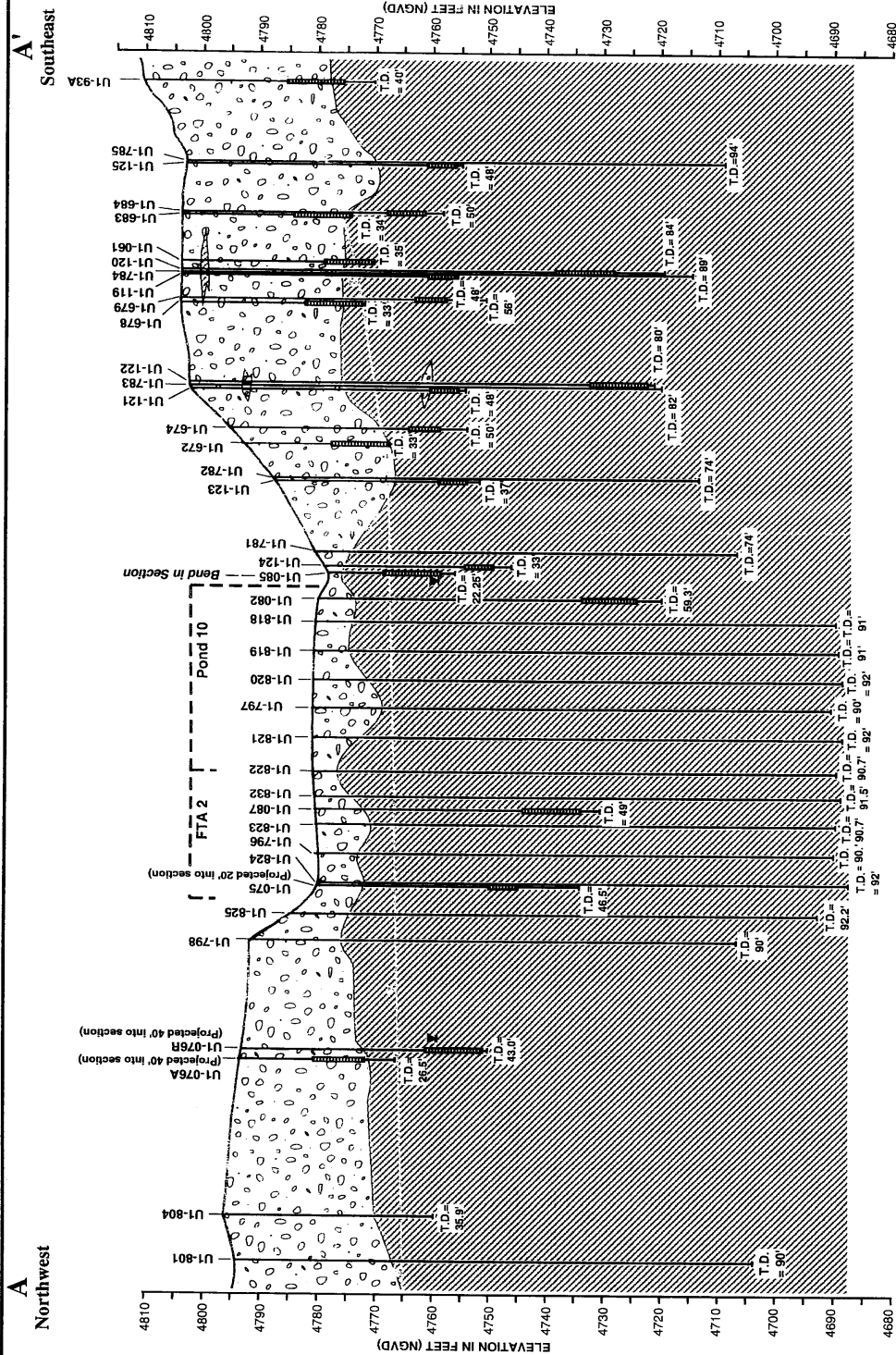


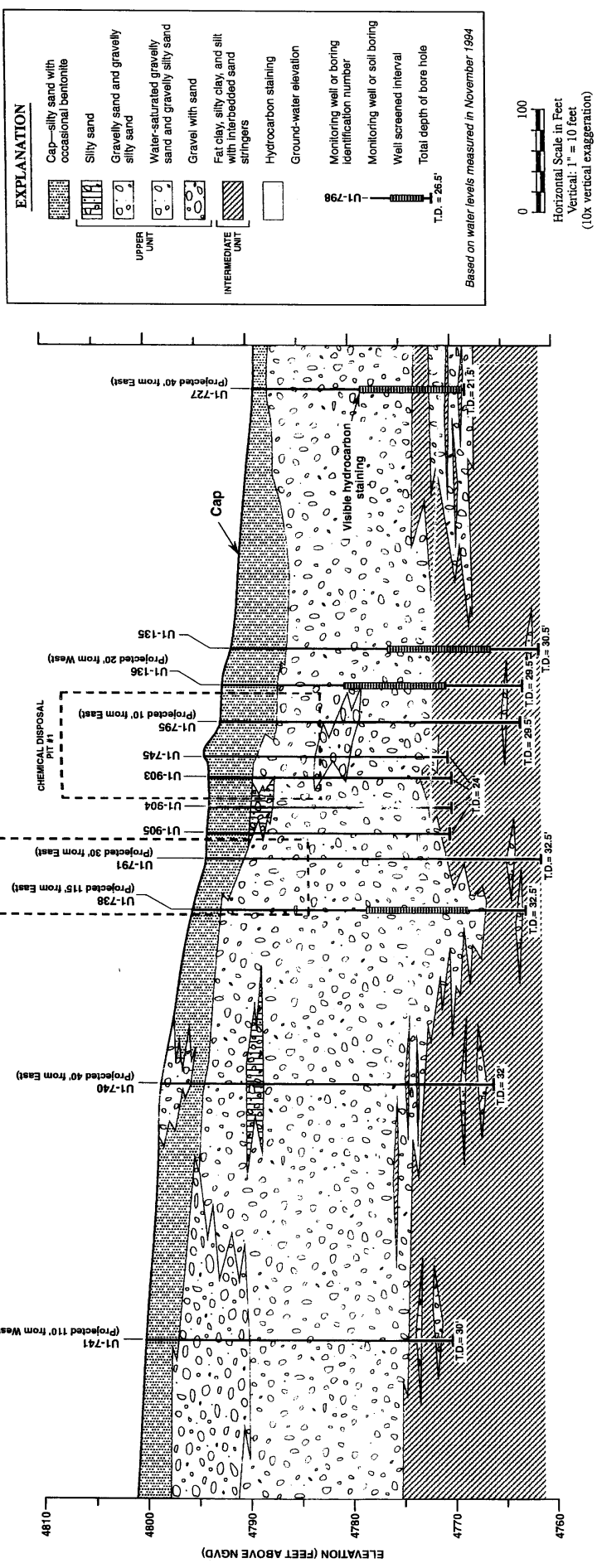
FIGURE 2.7

HYDROGEOLOGIC CROSS-SECTION A-A' OPERABLE UNIT 1

Hill Air Force Base, Utah

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B' North
B South



Note: Location of cross section shown in Figure 2-6

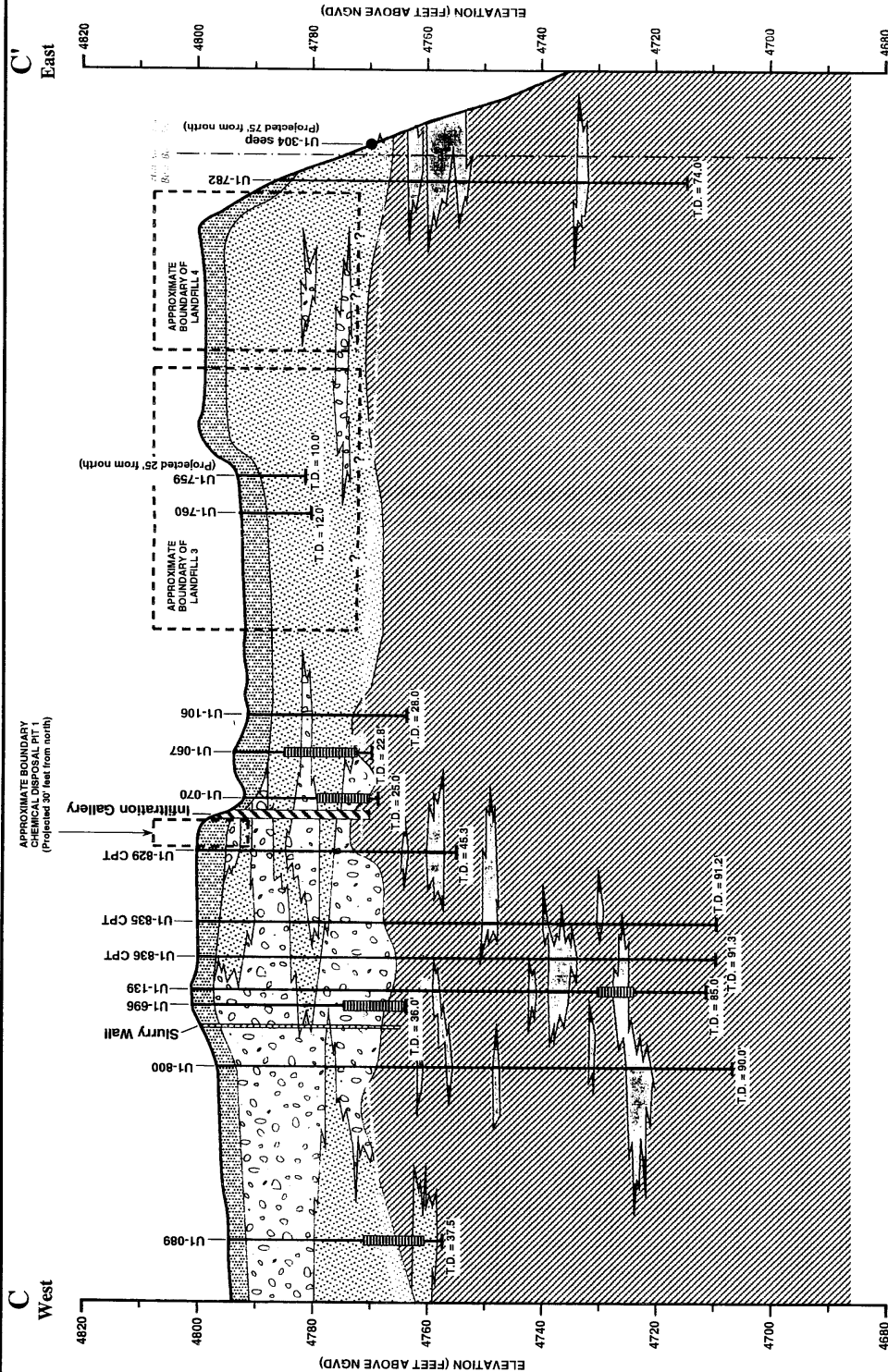
FIGURE 2.8

HYDROGEOLOGIC CROSS-SECTION B-B' OPERABLE UNIT 1

Hill Air Force Base, Utah

PARSONS ENGINEERING SCIENCE, INC.

Source: Montgomery Watson, 1995.



Note: Location of cross section shown in Figure 2-6

FIGURE 2.9

HYDROGEOLOGIC CROSS-SECTION C-C' OPERABLE UNIT 1

Hill Air Force Base, Utah

**PARSONS
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Source: Montgomery Watson, 1995.

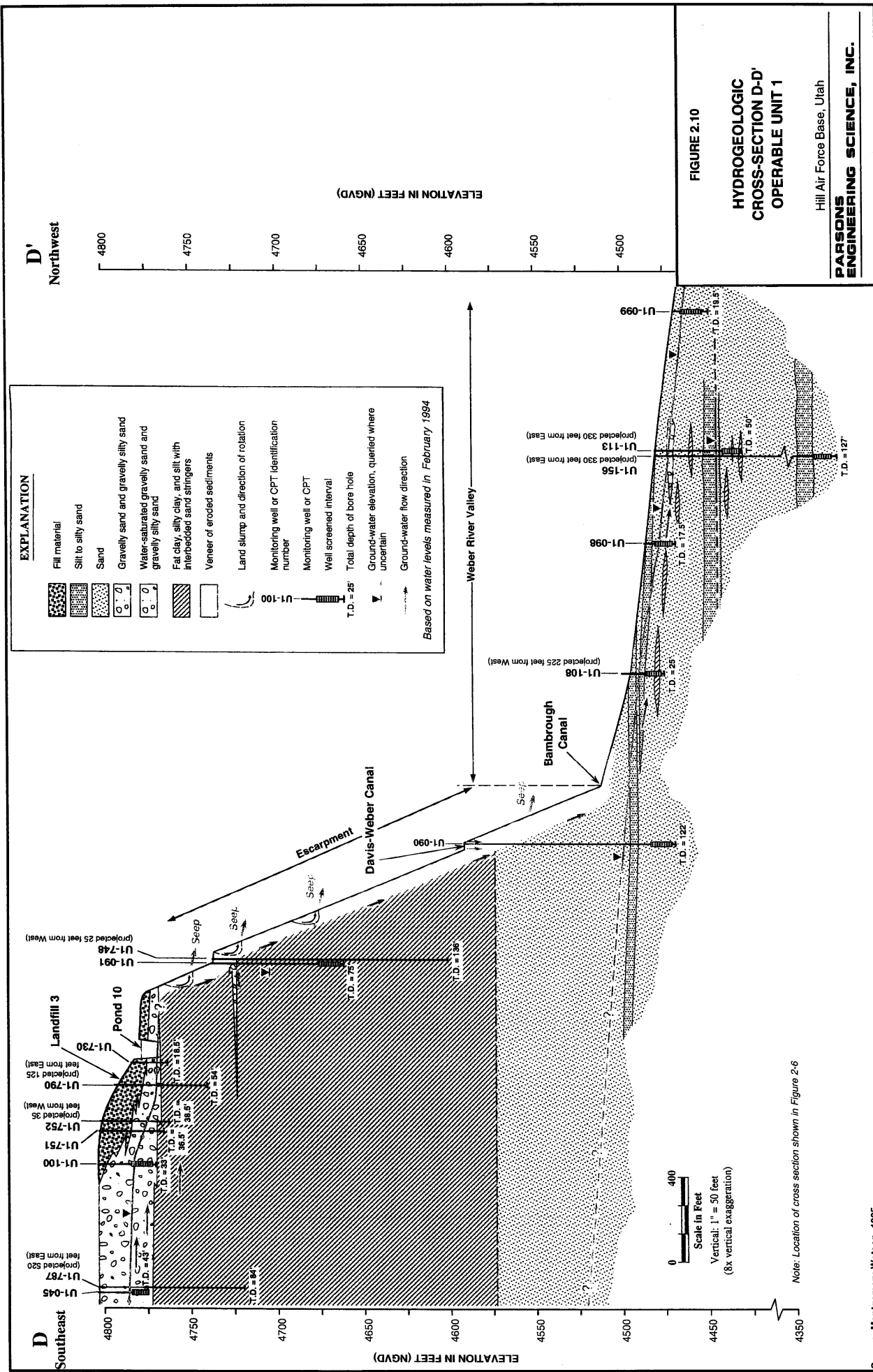
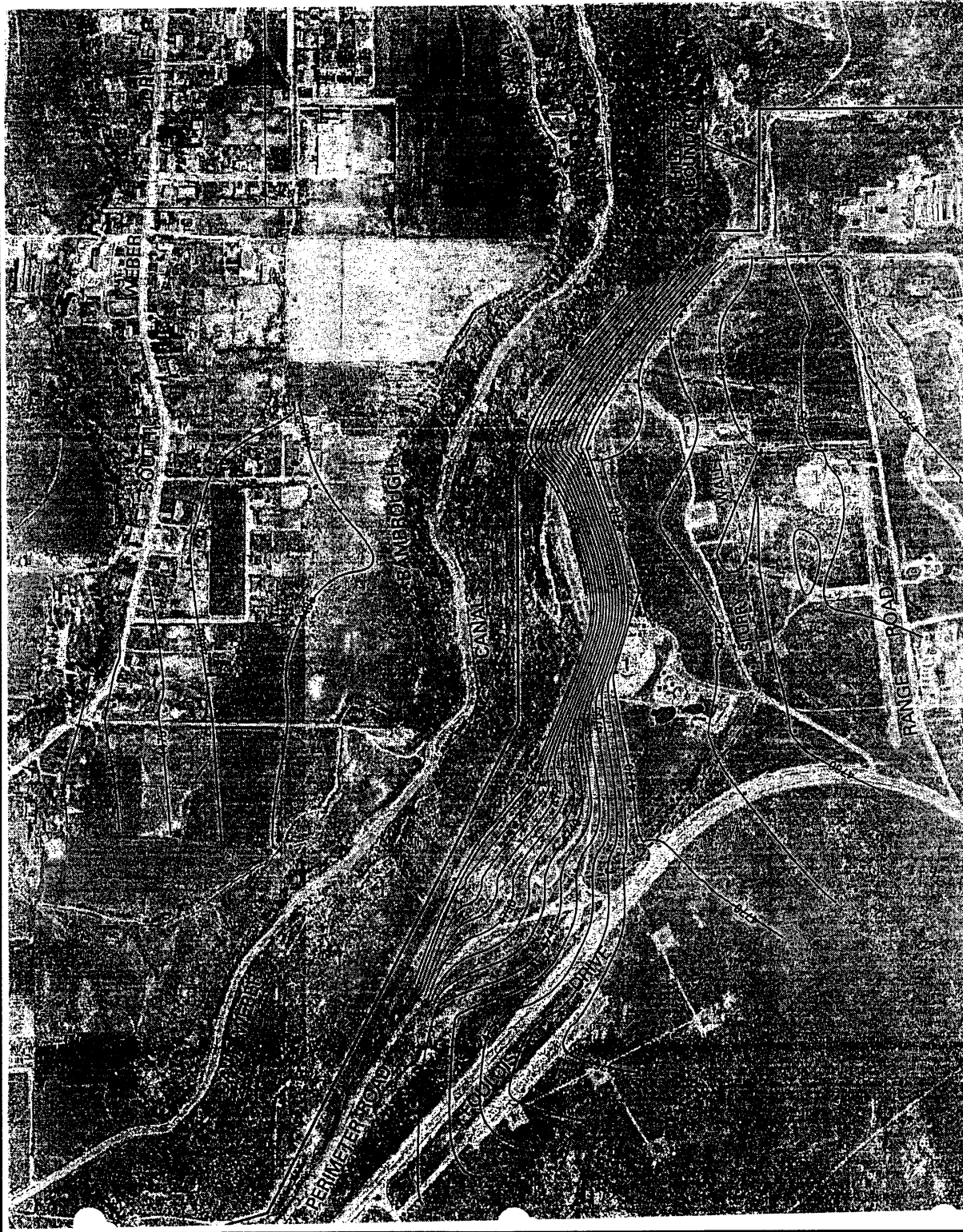


FIGURE 2.10

**HYDROGEOLOGIC
CROSS-SECTION D-D'
OPERABLE UNIT 1**

Hill Air Force Base, Utah

**PARSONS
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EXPLANATION

Monitoring wells UI-043, UI-062, UI-063, UI-075, UI-082, UI-083, UI-087, UI-088, UI-090, UI-091, UI-094, UI-095, UI-096, UI-113, UI-119, UI-120, UI-122, UI-124, UI-654, UI-659, UI-665, UI-674, UI-679, UI-684, UI-688, UI-692, are not included in the computer model that generated the ground-water contours because they are screened in the deeper portion of the shallow aquifer. However, ground-water elevations for these sites are included on the map.

• MONITORING WELL

— 4725 — GROUND-WATER CONTOUR ELEVATION

NOTE:

There are insufficient data points to correctly represent the groundwater elevation contours of the aquifer underlying the hillside adjoining OU 1. Therefore, monitoring wells UI-078, UI-084, UI-085, UI-086, and UI-103 have been deleted from the model.



FIGURE 2.12

WATER TABLE MAP OPERABLE UNIT 1

Hill Air Force Base, Utah

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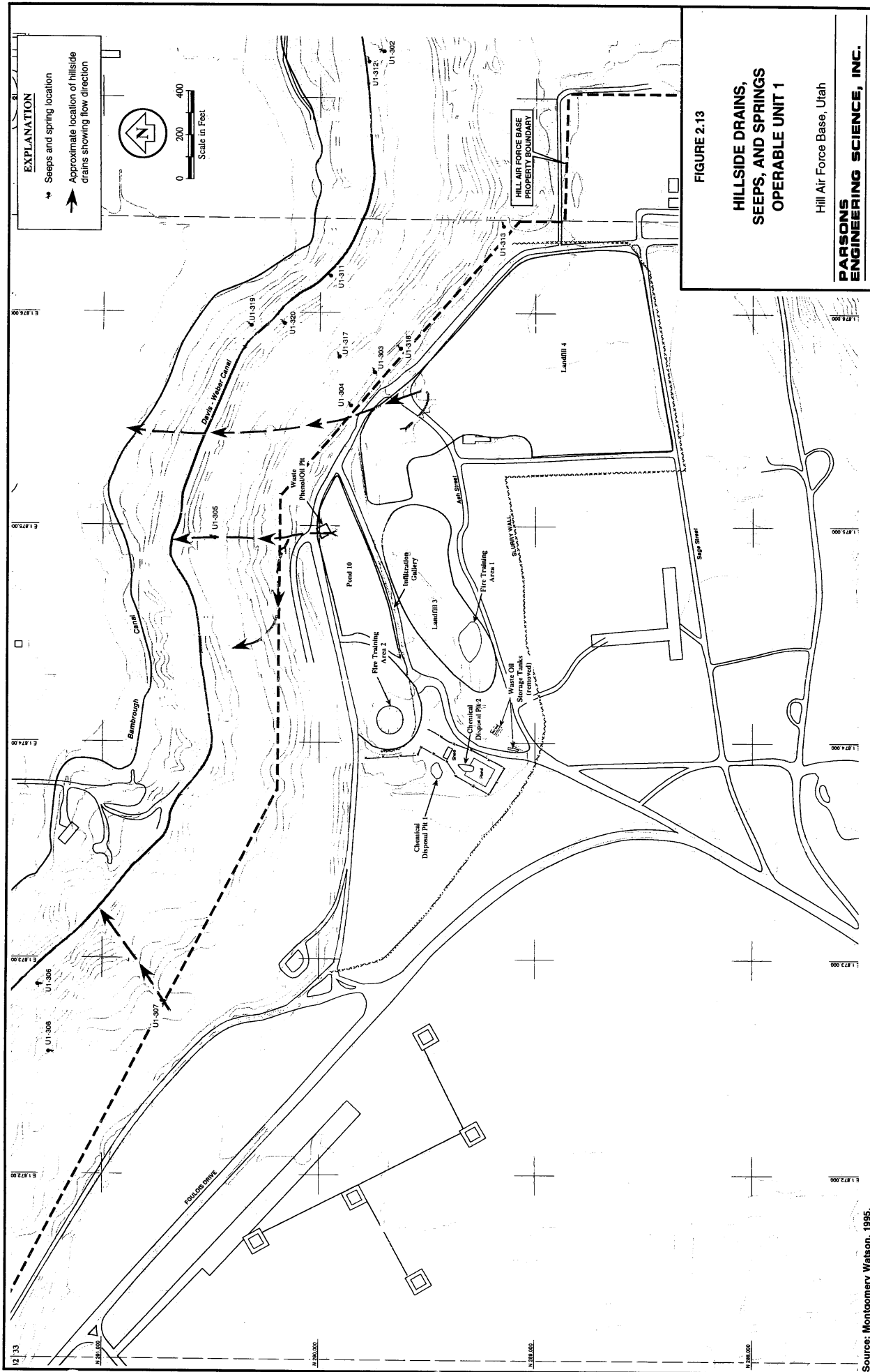


FIGURE 2.13

HILLSIDE DRAINS, SEEPS, AND SPRINGS, OPERABLE UNIT 1

Hill Air Force Base, Utah

PARSONS ENGINEERING SCIENCE, INC.

Source: Montgomery Watson, 1995.

and has notified the residents of the South Weber area regarding the risks associated with the use of groundwater from the shallow aquifer. The Town of South Weber has a deep production well located at 1600 East South Weber Drive.

The Davis-Weber Canal Company provides irrigation water to the area from the Davis-Weber canal, which flows past the OU 1 site (Figure 1.2). Water in the Davis-Weber Canal is used solely for irrigation.

Hydraulic conductivities in the shallow sand and gravel unit and intermediate silty clay unit were calculated from monitoring well slug tests and pump tests analyzed using the Bouwer and Rice (1976) method (Montgomery Watson, 1995) or the Hvorslev (1951) method (Radian and SAIC, 1988). The hydraulic conductivities of the saturated porous media adjacent to the screened interval of selected RI monitoring wells located on- and off-Base are presented in Table 2.1.

Hydraulic conductivity values calculated from slug tests in the upper sand and gravel unit on-Base ranged from about 2×10^{-2} to 8×10^{-5} cm/sec, with most values in the range of 2×10^{-4} to 5×10^{-4} cm/sec. Hydraulic conductivities calculated from pump test results from the same unit were consistently higher, ranging from 1.5×10^{-1} to 7×10^{-2} cm/sec. Regardless, the data indicate that hydraulic conductivities of the sand and gravel unit on-Base may vary over three orders of magnitude. Hydraulic conductivities measured in the on-Base portion of the silty clay unit ranged from 1×10^{-5} to 2×10^{-4} cm/sec, with values in half the wells being about 2×10^{-5} cm/sec.

The hydraulic conductivities calculated from the slug tests performed in off-Base wells screened in sandy or silty soils ranged from 1×10^{-3} to 4×10^{-5} cm/sec. For wells screened in clay the calculated hydraulic conductivities ranged from 1×10^{-5} to 4×10^{-5} cm/sec.

The average hydraulic gradient at OU 1 was approximately 0.01 foot/foot (ft/ft) on-Base south of the Davis-Weber Canal escarpment; 0.23 ft/ft down the Davis-Weber Canal escarpment; and 0.02 ft/ft in the Town of South Weber area. These values were calculated on the basis of the June 1994 groundwater surface (Figure 2.12).

Vertical well pairs screened in the upper and lower portions of the surficial aquifer located on-Base in the OU 1 area indicate an average downward vertical hydraulic gradient of 0.25 ft/ft.

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

$$\bar{v} = \frac{K}{n_e} \frac{dH}{dL}$$

Where: \bar{v} = Average advective groundwater velocity (seepage velocity)
[L/T] (ft/day)

TABLE 2.1
SUMMARY OF HYDRAULIC CONDUCTIVITY TESTING RESULTS
Hill Air Force Base, Utah

Well Number	Estimated	Estimated	Estimated	Calculated	Aquifer Material Adjacent to Screened Interval	Depth of Screened Interval (ft bgl) ^{a/}	Type of Test
	Horizontal Hydraulic Conductivity (cm/sec)	Horizontal Hydraulic Conductivity (ft/day)	Horizontal Hydraulic Gradient (ft/ft)	Average Linear Horizontal Velocity (ft/yr)			
ON-BASE UPPER SAND GRAVEL UNIT							
U1-050 ^{b/}	8 x 10 ⁻⁵	0.2	0.09	25	Sand with clay and silt	Unknown	Slug
U1-093 ^{b/}	3 x 10 ⁻³	8.5	0.09	1000	Sand with gravel	24 - 34	Slug
U1-116	4 x 10 ⁻⁴	1.1	0.02	30	Sand/clay	22 - 32	Slug
U1-117	4 x 10 ⁻⁴	1.1	0.06	80	Sand with gravel/clay	37 - 47	Slug
U1-119	2 x 10 ⁻³	5.7	0.08	600	Silty sand to sand	43 - 48	Slug
U1-121	6 x 10 ⁻⁴	1.7	0.12	300	Silty sand	42 - 47	Slug
U1-123	5 x 10 ⁻⁴	1.4	0.1	200	Silt/silty sand	30 - 35	Slug
U1-125	2 x 10 ⁻⁴	0.6	0.09	100	Silty sand/some gravel	42 - 47	Slug
U1-132	3 x 10 ⁻⁴	0.9	0.09	93	Sand	18 - 28	Slug
U1-645	5 x 10 ⁻⁴	1.4	0.01	20	Silty sand/some gravel	20 - 30	Slug
U1-646	4 x 10 ⁻⁴	1.1	0.01	10	Silty sand/some gravel	21 - 31	Slug
U1-648	1 x 10 ⁻³	2.8	0.01	40	Silty sand/some gravel	23 - 33	Slug
U1-649	2 x 10 ⁻²	56.7	0.01	700	Sand	22 - 32	Slug
U1-118	3 x 10 ⁻²	85.1	0.009	931	Sand/Clay	24 - 34	Pump
U1-140	1.5 x 10 ⁻¹	425.3	0.009	4656	Sand with gravel	26 - 36	Pump
U1-143	1 x 10 ⁻²	28.4	0.009	310	Sand/Clay	25 - 35	Pump
U1-655	4 x 10 ⁻²	113.4	0.01	1380	Sand with gravel	13 - 23	Pump
U1-658	1 x 10 ⁻²	28.4	0.01	345	Sand with gravel	13 - 23	Pump
U1-696	7 x 10 ⁻²	198.5	0.009	2173	Sand with gravel	26 - 36	Pump
U1-670	4 x 10 ⁻²	113.4	0.017	2345	Sand with gravel	22 - 32	Pump
U1-671	6 x 10 ⁻²	170.1	0.017	3518	Sand with gravel	22 - 32	Pump
ON-BASE SILTY CLAY UNIT							
U1-043A ^{b/}	2 x 10 ⁻⁵	0.1	0.16	7	Clay	43 - 58	Slug
U1-062 ^{b/}	2 x 10 ⁻⁵	0.1	0.009	0.4	Clay with fine sand lenses	33 - 43	Slug
U1-063 ^{b/}	2 x 10 ⁻⁵	0.1	0.1	4	Clay with fine sand lenses	35 - 45	Slug
U1-088A ^{c/}	4 x 10 ⁻⁵	0.1	0.009	1	Clay with fine sand lenses	64 - 74	Slug
U1-120	1 x 10 ⁻⁵	0	0.08	2	Clay with fine sand lenses	65 - 75	Slug
U1-122	2 x 10 ⁻⁴	0.6	0.12	50	Clay with fine sand lenses	68 - 78	Slug
U1-124	2 x 10 ⁻⁵	0.1	0.16	7	Clay with fine sand lenses	25 - 30	Slug
U1-040	3 x 10 ⁻⁵	0.1	0.16	10	Clay with fine sand lenses	73 - 94	Slug
OFF-BASE SHALLOW SOIL							
U1-090 ^{c/}	6 x 10 ⁻⁴	1.7	0.01	28	Sand	109 - 119	Slug
U1-091 ^{c/}	1 x 10 ⁻⁵	0	0.01	0.5	Clay	62 - 72	Slug
U1-094 ^{c/}	1 x 10 ⁻³	2.8	0.01	46	Sand with silt	54 - 64	Slug
U1-095 ^{c/}	8 x 10 ⁻⁴	2.3	0.01	37	Sand	33 - 43	Slug
U1-096 ^{c/}	4 x 10 ⁻⁵	0.1	0.01	2	Sand with silt	32 - 42	Slug
U1-097 ^{c/}	1 x 10 ⁻³	2.8	0.01	46	Sand with silt	9 - 19	Slug
U1-098 ^{c/}	4 x 10 ⁻³	11.3	0.01	184	Sand	4 - 14	Slug
U1-099 ^{c/}	4 x 10 ⁻⁵	0.1	0.01	2	Clay with silt	4.6 - 14.6	Slug

^{a/} ft bgl = Feet below ground level

^{b/} From Radian and SAIC (1988); values calculated using method of Hvorslev (1951)

^{c/} Measured by Montgomery Watson; values calculated using method of Bouwer and Rice (1976)

Source: Montgomery Watson, 1995.

K = Hydraulic conductivity [L/T]

dH/dL = Gradient [L/L]

n_e = Effective porosity.

Using this relationship in conjunction with the site-specific data given in Table 2.1, Montgomery Watson (1995) calculated the average advective groundwater velocities presented in Table 2.1. Because hydraulic conductivities vary by three orders of magnitude among subunits of the shallow aquifer, groundwater velocities vary significantly across the site. As part of the RNA evaluation, borehole flowmeters will be used to further define these parameters.

A summary of the vertical hydraulic conductivities and average vertical velocities for samples collected from the clay unit beneath OU 1 is presented in Table 2.2. These values show a variation of about one order of magnitude, and the calculated vertical velocities are about 3 orders of magnitude lower than the average vertical velocity.

2.1.3 Nature and Extent of Contamination at OU 1

As discussed in Section 1, sites at OU 1 have hosted a variety of activities that have contributed to site soil and groundwater contamination. A review of the historical chemical usage at Hill AFB is displayed in Figure 2.14. The following discussion focuses on the soil and groundwater contamination present in the OU 1 area and provides a summary of the nature, extent, and concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) and CAHs in these media in this source area and in hydraulically downgradient, off-Base locations. Included in this discussion are the site conceptual model of the release, fate, and transport of contamination based on hydrogeologic conditions, the nature and distribution of contaminants, and geochemistry. Results are summarized primarily from the RI that Montgomery Watson (1995) performed at OU 1.

2.1.3.1 Soil Gas and Soil Contamination

During the performance of the RI at OU 1, a Level II soil gas survey was conducted to identify potential source areas of VOC contamination originating from the OU 1 sites, to evaluate the extent of contaminant migration in the shallow aquifer, and to help determine the locations of future off-Base monitoring wells. The soil gas samples, taken from a 150-acre area north of the source areas at OU 1 including the Davis-Weber Canal escarpment area and the Weber River Valley, were analyzed by photoionization detector (PID) for benzene, toluene, *trans*-1,2-dichloroethene (*trans*-1,2-DCE), trichloroethane (TCA), and 1,1-dichloroethane (DCA). Subsequent to these analyses, *cis*-1,2-DCE concentrations were estimated from *trans*-1,2-DCE results, and confirmed by gas chromatography/mass spectroscopy and similar sensitivity of the PID to *trans*- and *cis*-1,2-DCE. *cis*-1,2-DCE and *trans*-1,2-DCE concentrations in soil gas are presented in Figures 2.15 and 2.16, respectively. The presence of *cis*-1,2-DCE, a major byproduct of reductive dehalogenation of trichloroethene (TCE), in

TABLE 2.2
SUMMARY OF VERTICAL HYDRAULIC CONDUCTIVITY AND AVERAGE
LINEAR VELOCITY TESTING RESULTS
Hill Air Force Base, Utah

Well Number	Depth of Geotechnical Sample (ft bgl) ^{a/}	Calculated Vertical Hydraulic Conductivity (cm/sec)	Calculated Vertical Hydraulic Conductivity (ft/day)	Average Linear Vertical Velocity (ft/yr) ^{b/}	Aquifer Material Adjacent to Screened Interval
U1-083	40	1.5×10^{-8}	4.3×10^{-5}	0.014	Intermediate clay unit
U1-139	45	2.2×10^{-7}	6.2×10^{-4}	0.240	Intermediate clay unit
U1-142	45	3.1×10^{-8}	8.8×10^{-5}	0.015	Intermediate clay unit
U1-142	55	5.0×10^{-8}	1.4×10^{-4}	0.024	Intermediate clay unit
U1-797	20	5.1×10^{-8}	1.4×10^{-4}		Intermediate clay unit
U1-798	25	2.9×10^{-8}	8.2×10^{-5}		Intermediate clay unit
U1-800	35	3.4×10^{-8}	9.6×10^{-5}		Intermediate clay unit
U1-801	30	4.0×10^{-8}	1.1×10^{-4}		Intermediate clay unit
U1-802	30	6.4×10^{-8}	1.8×10^{-4}		Intermediate clay unit
SB-22D	11	5.3×10^{-6}	1.5×10^{-2}		Intermediate clay unit
SB-22D	15	6.6×10^{-8}	1.9×10^{-4}		Intermediate clay unit
SB-22D	25	1.3×10^{-7}	3.7×10^{-4}		Intermediate clay unit
SB-23D	14.5	1.4×10^{-7}	4.0×10^{-4}		Intermediate clay unit
SB-23D	17.5	1.3×10^{-5}	3.7×10^{-2}		Intermediate clay unit

^{a/} ft bgl = Feet below ground level

^{b/} Average linear vertical velocity could be calculated only at wells where there are vertical hydraulic conductivity tests associated with a vertical hydraulic gradient. Vertical hydraulic conductivities were calculated in the Dames & Moore Geotechnical Laboratory.

Source: Montgomery Watson, 1995.

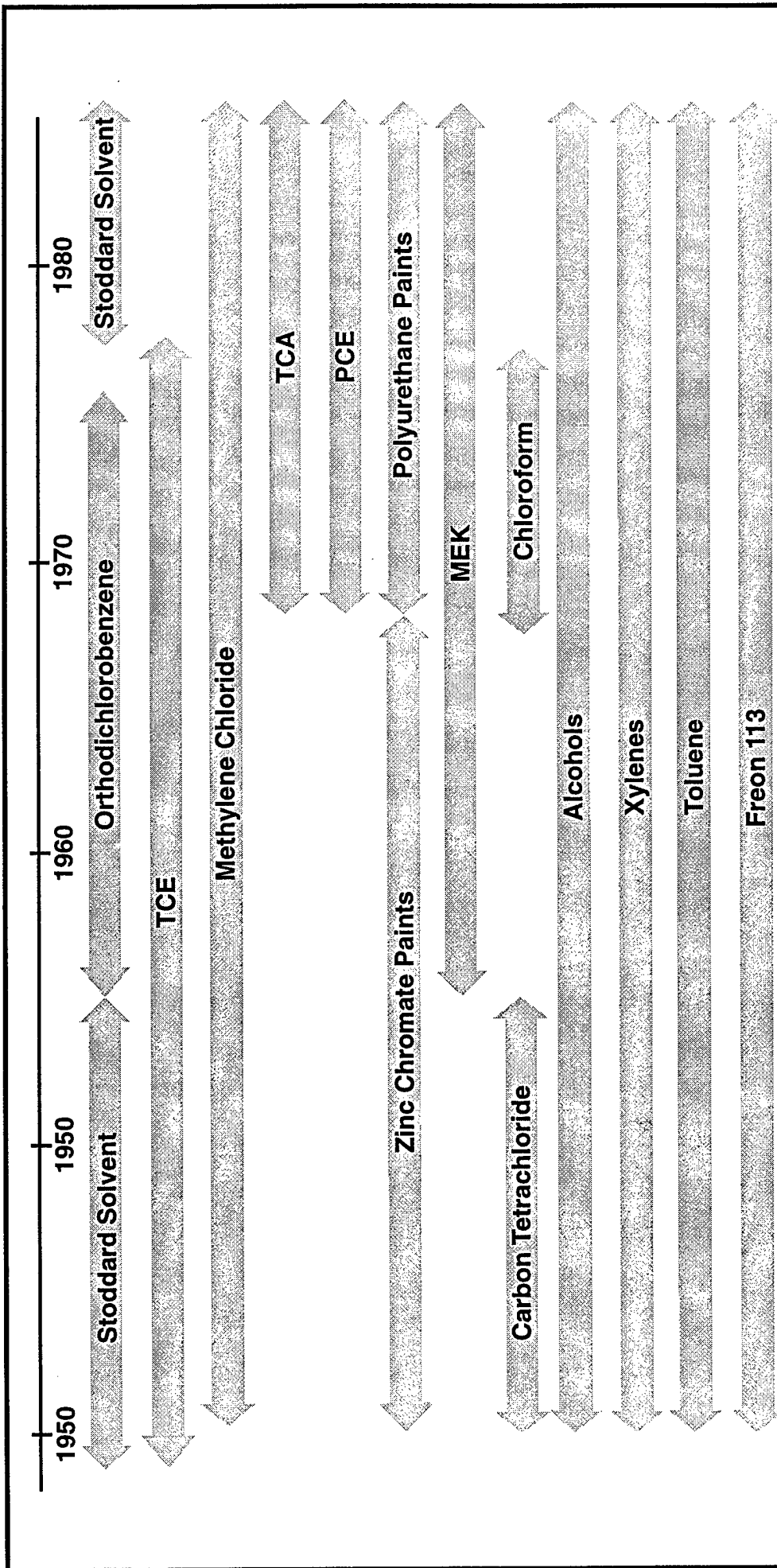
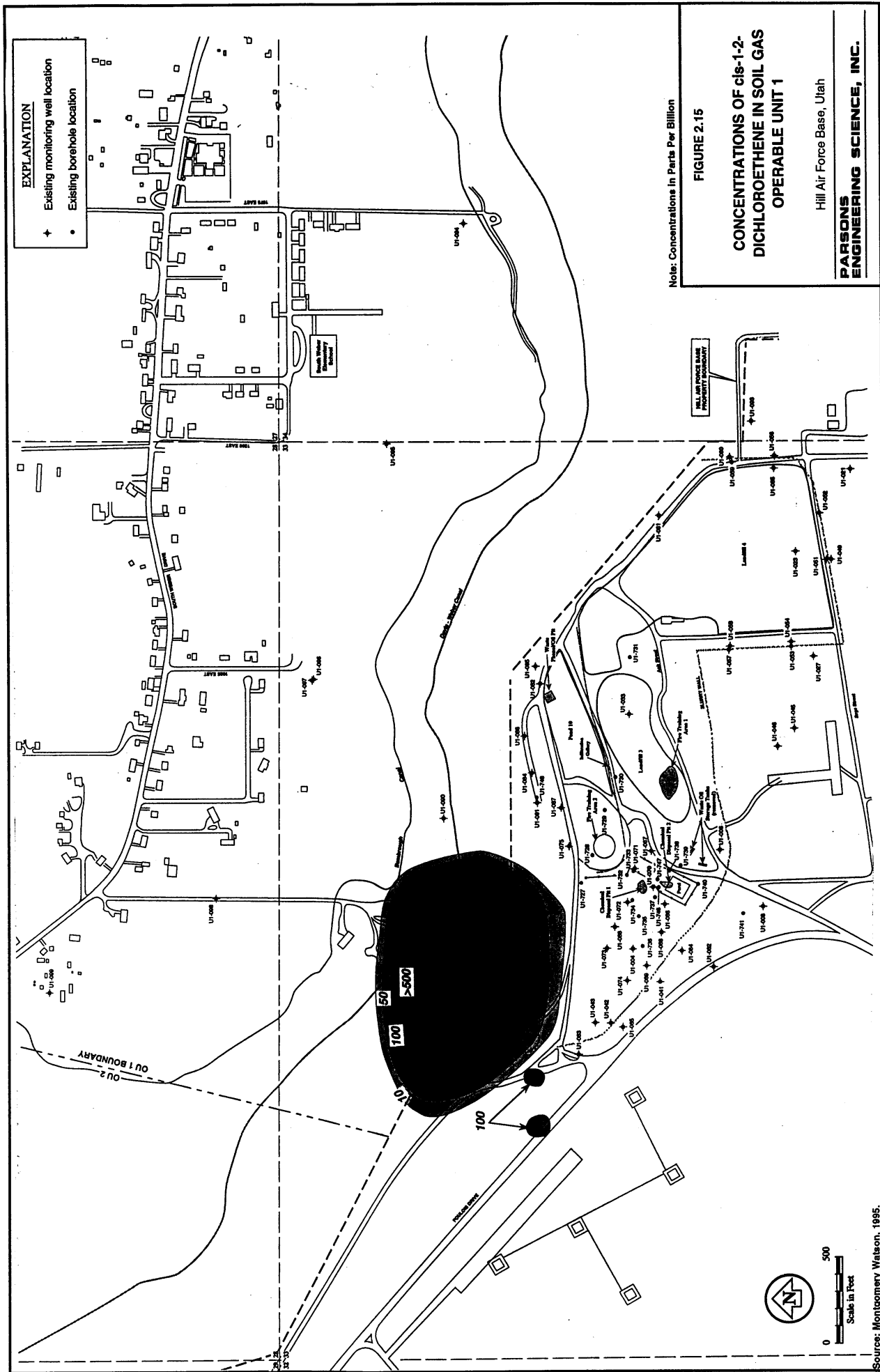


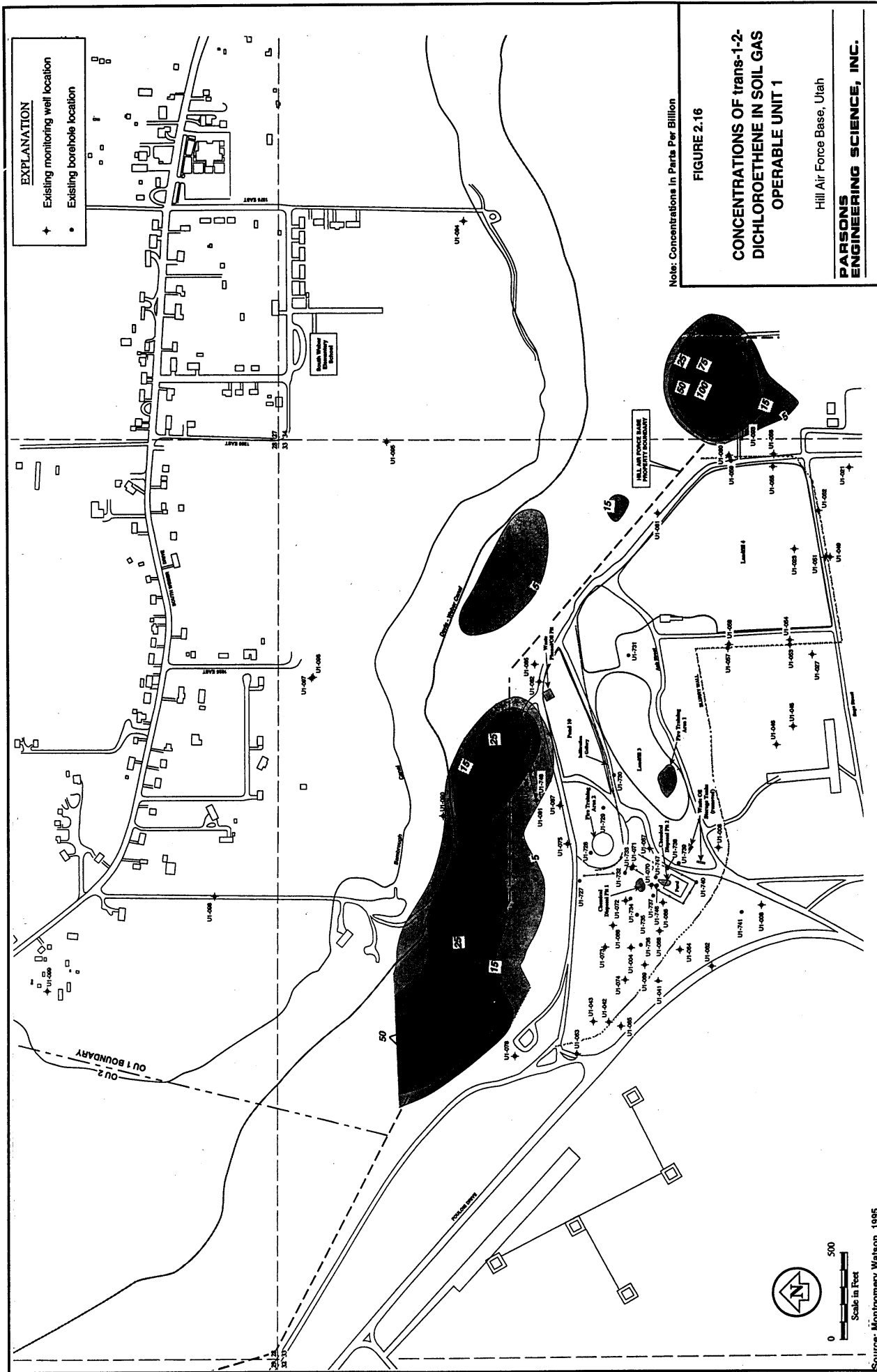
FIGURE 2.14

HISTORIC CHEMICAL USAGE

Hill Air Force Base, Utah

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concentrations greater than the *trans* isomer by an order of magnitude may be evidence of biodegradation of TCE.

Subsurface soil contamination at OU 1 sites was evaluated during drilling activities associated with the RI (Montgomery Watson, 1995). Soil samples from several depths, ranging from 0 to 36 feet bgl, at 49 locations were analyzed for various compounds, including halogenated volatiles, aromatic volatiles, metals, alkalinity, and total organic carbon (TOC). Soil sample locations, depth intervals, and analyses performed have been summarized by Montgomery Watson (1995). Results of the soil analyses are discussed in the following paragraphs, grouped by potential source areas.

In the area of CDPs 1 and 2, VOCs most frequently detected were chlorinated hydrocarbons and petroleum hydrocarbons. The highest concentrations of chlorinated hydrocarbons were detected in soils obtained from the LNAPL smear zone (Section 2.1.3.2) created by fluctuations in groundwater levels, in the capillary fringe, and the upper portion of the shallow aquifer. The most commonly detected chlorinated hydrocarbons were chlorobenzenes, 1,1,1-TCA, tetrachloroethene (PCE), and TCE. The highest detected concentrations of these compounds were: 1,2,4-trichlorobenzene at 19,000 micrograms per kilogram ($\mu\text{g/kg}$); 1,2-dichlorobenzene (DCB) at 170,000 $\mu\text{g/kg}$; 1,4-DCB at 21,000 $\mu\text{g/kg}$; 1,1,1-TCA at 8,100 $\mu\text{g/kg}$; PCE at 9,100 $\mu\text{g/kg}$; and TCE at 9,100 $\mu\text{g/kg}$. The most frequently detected fuel hydrocarbons, ethylbenzene, naphthalene, toluene, and xylenes, were detected in the highest concentrations in the capillary fringe and upper portion of the shallow aquifer. Concentrations for the commonly detected fuel hydrocarbons ranged up to 2,100 $\mu\text{g/kg}$ of ethylbenzene, 6,900 $\mu\text{g/kg}$ of naphthalene, 5,500 $\mu\text{g/kg}$ of toluene, and 4,700 $\mu\text{g/kg}$ of xylenes. The highest concentrations of base-neutral, acid -extractable compounds (BNAEs) were frequently detected at the same sample locations, and at the same sample intervals where VOCs were detected. The extent of VOC and BNAE contamination in the subsurface at CDPs 1 and 2 is depicted in Figure 2.17.

At LF 3, chlorinated benzenes were detected at the highest concentrations. Other VOCs detected were naphthalene, 1,2-DCE (no isomers reported), and xylenes. A wide range of BNAEs, including pentachlorophenol, were found to be present in the soil. Pesticides, PCBs, dioxins, and furans again were found in soil samples in trace amounts. No metals were detected at concentrations significantly higher than background. At LF 4 the VOCs 1,1-DCA, PCE, 1,2-DCE, and TCE were detected in soil samples at levels above respective practical quantitation limits. The highest concentrations of PCE (55 $\mu\text{g/kg}$), TCE (190 $\mu\text{g/kg}$), and 1,2-DCE (1,600 $\mu\text{g/kg}$) were detected at a depth of 6 to 8 feet bgl. The BNAEs detected in soil samples from LF 4 included 2-methylnaphthalene, phenanthrene, chrysene, and benzo(a)pyrene. BNAEs were detected in the same soil sample in which the highest levels of VOCs were found.

Soil samples were taken near FTA 1 as monitoring wells were being drilled upgradient and downgradient from FTA 1, and four soil borings were drilled within FTA 1. Samples at two depth intervals from each borehole were collected for VOC, BNAE, pesticide, PCB, total petroleum hydrocarbons (TPH), and metals analyses.

concentrations greater than the *trans* isomer by an order of magnitude may be evidence of biodegradation of TCE.

Subsurface soil contamination at OU 1 sites was evaluated during drilling activities associated with the RI (Montgomery Watson, 1995). Soil samples from several depths, ranging from 0 to 36 feet bgl, at 49 locations were analyzed for various compounds, including halogenated volatiles, aromatic volatiles, metals, alkalinity, and total organic carbon (TOC). Soil sample locations, depth intervals, and analyses performed have been summarized by Montgomery Watson (1995). Results of the soil analyses are discussed in the following paragraphs, grouped by potential source areas.

In the area of CDPs 1 and 2, VOCs most frequently detected were chlorinated hydrocarbons and petroleum hydrocarbons. The highest concentrations of chlorinated hydrocarbons were detected in soils obtained from the LNAPL smear zone (Section 2.1.3.2) created by fluctuations in groundwater levels, in the capillary fringe, and the upper portion of the shallow aquifer. The most commonly detected chlorinated hydrocarbons were chlorobenzenes, 1,1,1-TCA, tetrachloroethene (PCE), and TCE. The highest detected concentrations of these compounds were: 1,2,4-trichlorobenzene at 19,000 micrograms per kilogram ($\mu\text{g/kg}$); 1,2-dichlorobenzene (DCB) at 170,000 $\mu\text{g/kg}$; 1,4-DCB at 21,000 $\mu\text{g/kg}$; 1,1,1-TCA at 8,100 $\mu\text{g/kg}$; PCE at 9,100 $\mu\text{g/kg}$; and TCE at 9,100 $\mu\text{g/kg}$. The most frequently detected fuel hydrocarbons, ethylbenzene, naphthalene, toluene, and xylenes, were detected in the highest concentrations in the capillary fringe and upper portion of the shallow aquifer. Concentrations for the commonly detected fuel hydrocarbons ranged up to 2,100 $\mu\text{g/kg}$ of ethylbenzene, 6,900 $\mu\text{g/kg}$ of naphthalene, 5,500 $\mu\text{g/kg}$ of toluene, and 4,700 $\mu\text{g/kg}$ of xylenes. The highest concentrations of base-neutral, acid -extractable compounds (BNAEs) were frequently detected at the same sample locations, and at the same sample intervals where VOCs were detected. The extent of VOC and BNAE contamination in the subsurface at CDPs 1 and 2 is depicted in Figure 2.17.

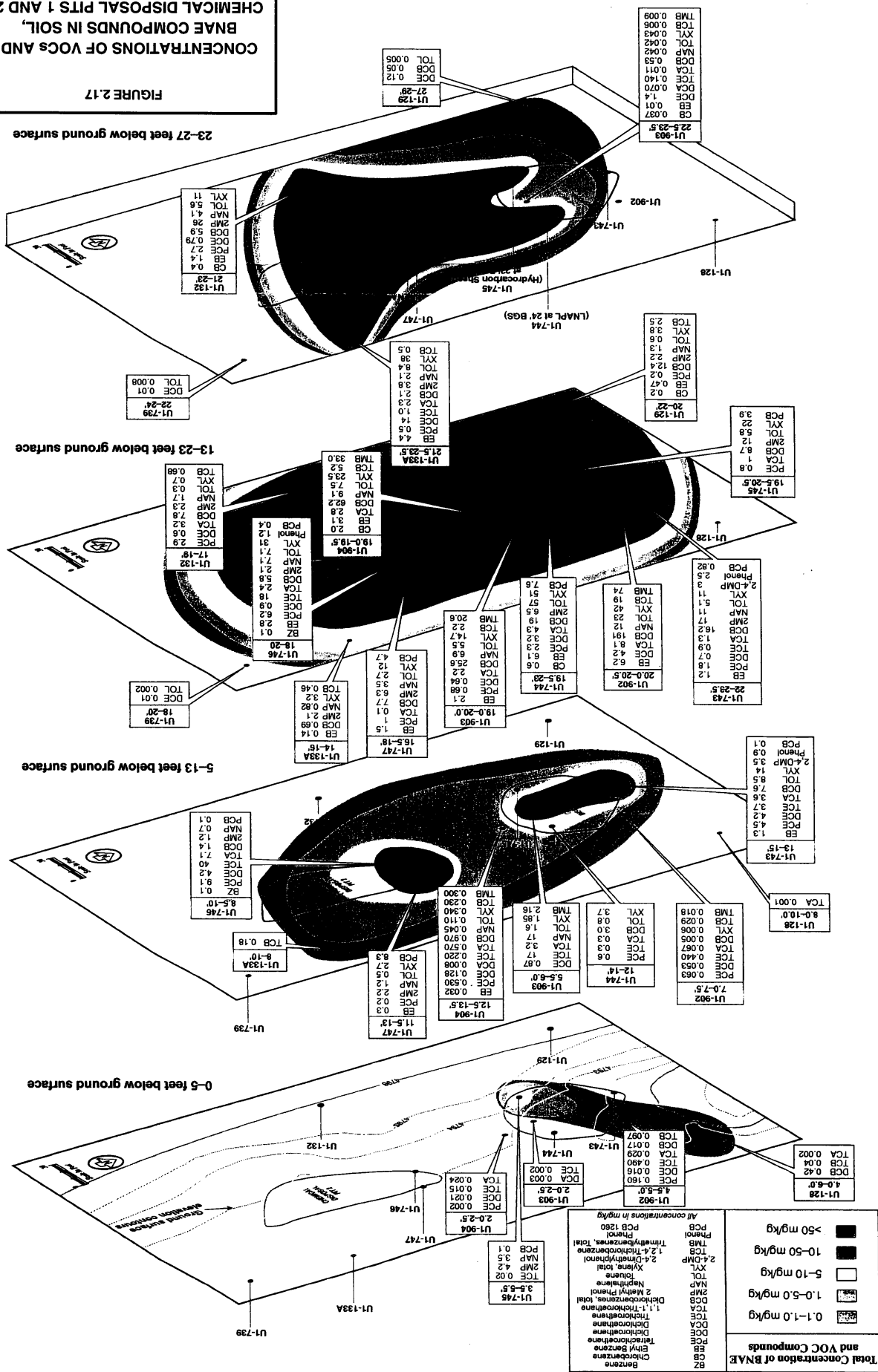
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Soil samples were taken near FTA 1 as monitoring wells were being drilled upgradient and downgradient from FTA 1, and four soil borings were drilled within FTA 1. Samples at two depth intervals from each borehole were collected for VOC, BNAE, pesticide, PCB, total petroleum hydrocarbons (TPH), and metals analyses.

Hill Air Force Base, Utah

**CONCENTRATIONS OF VOCs AND
BNAE COMPOUNDS IN SOIL,
CHEMICAL DISPOSAL PITS 1 AND 2**

FIGURE 2.17



One sample also was analyzed for dioxins, furans, and TOC. Chlorinated and petroleum VOCs were detected in a portion of the samples; however, petroleum VOCs were detected more often and at higher concentrations. Of the petroleum hydrocarbons, ethylbenzene, xylenes, 1,2,4-trichlorobenzene, and 1,2-DCB were detected at levels ranging up to 3,500 µg/kg, 37,000 µg/kg, 41,000 µg/kg, and 15,000 µg/kg, respectively. PCE and TCE were detected in one sample at 11 µg/kg and 1.9 µg/kg, respectively. TPH in the soil ranged from 270 milligrams per kilogram (mg/kg) to 3,200 mg/kg.

During drilling activities near FTA 2, soil samples were taken from 2 depth intervals at 12 locations. The samples were analyzed for various parameters, including VOCs, BNAEs, and TPH. Several samples were analyzed only for TPH. Appendix A contains information on the analytical methods used for soil analyses. Xylenes, naphthalene, and ethylbenzene were the most frequently detected VOCs. TCE and 1,2-DCE were found at concentrations ranging up to 43 µg/kg and 32 µg/kg, respectively.

Two soil borings were drilled near the WPOP during the RI. A total of three soil samples were collected for VOC, BNAE, pesticide, PCB, TPH, and metals analysis, while two of the samples were analyzed for dioxins, furans, and TOC. TCE, 1,2-DCE, and chlorinated benzenes were the only VOCs detected in the three soil samples. TCE and 1,2-DCE concentrations ranged up to 1,400 µg/kg and 92 µg/kg, respectively. Of the BNAEs, pentachlorophenol and pyrene were detected at concentrations of 240 µg/kg and 52 µg/kg, respectively.

During the drilling of two soil borings at the WOST area, samples were collected for VOC, BNAE, pesticide, PCB, TPH, and metals analysis. TCE, 1,2-DCE, benzene, xylenes, and naphthalene were detected. Trace amounts of pesticides and PCBs, and concentrations of metals approximately equal to background levels were detected in these soil samples.

In summary, concentrations of chlorinated and petroleum hydrocarbons were detected in soil samples collected throughout the site. The more ubiquitous chlorinated hydrocarbons included TCE, 1,2-DCE, and chlorinated benzenes. BTEX, as well as naphthalene, pesticides, PCBs, furans, and dioxins, were frequently detected in soil samples collected at OU 1. Typically the pesticides and PCBs were found near the ground surface (0-5 feet bgl). Furans and dioxins were found at shallow depths in areas where the combustion of chlorinated solvent and fuel hydrocarbons had taken place (i.e., at the fire training areas). Chlorinated and fuel hydrocarbons were generally detected at depths near LNAPL, in the capillary fringe, and in the upper portion of the shallow aquifer.

2.1.3.2 Presence of LNAPL

A layer of LNAPL is present above groundwater over a large portion of the shallow water table in the OU 1 area. The thickness of the LNAPL layer has been measured periodically since May 1990 (Figure 2.18). As of April 1994, the LNAPL layer extends from FTA 1, through the vicinity of CDPs 1 and 2, to Foulis Drive west of



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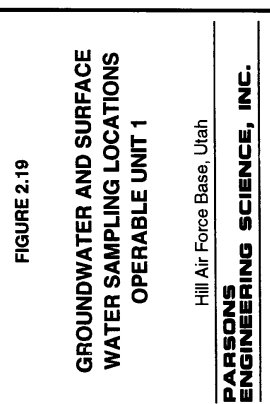
CDPs 1 and 2. Samples of LNAPL were collected from monitoring wells U1-004 (M-27-LF), downgradient of the CDPs, and U1-101 (W-4-LF), immediately downgradient of FTA 1. The samples were analyzed for VOCs, BNAEs, pesticides/PCBs, and dioxins/furans. Chlorobenzene, naphthalene, 1,2-DCE, 1,1,1-TCA, PCE, toluene, total xylenes, 1,2-dichlorobenzene, 2-methylnaphthalene, various pesticides, and PCBs were detected. Acetone also was detected in the LNAPL sample from U1-004, but is not considered representative of the environment. These results are included in Appendix A. The estimated areal extent of LNAPL is 9.3 acres, and baildown test results suggest the true LNAPL thickness ranges from 0.02 to 0.53 foot (Montgomery Watson, 1995).

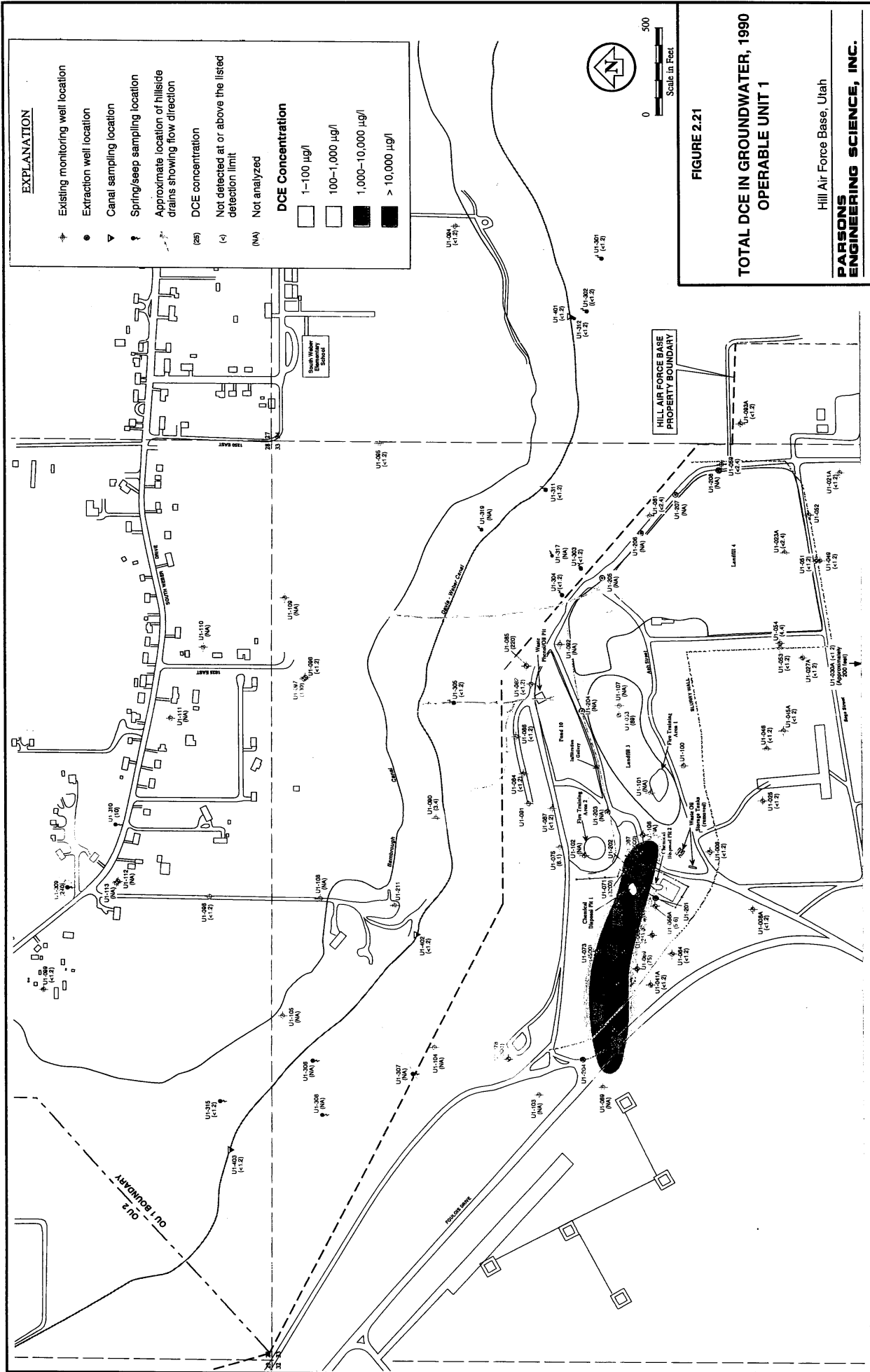
2.1.3.3 Groundwater Contamination

Appendix A contains a partial listing of organic compounds detected in groundwater samples from selected wells at OU 1 from April 1990 to May 1994. Figure 2.19 shows groundwater and surface water sampling locations at OU 1. CAHs detected in groundwater samples from OU 1 include TCE, PCE, 1,2-DCE, vinyl chloride (VC), 1,1,1-TCA, 1,1-DCA, and 1,2-DCA. Petroleum hydrocarbons detected in OU 1 groundwater include BTEX compounds and naphthalene. Other VOCs detected in site groundwater include chlorobenzene, 1,2,4-trichlorobenzene, 1,4-DCB, and 1,2-DCB. Figure 2.20 shows the distribution of CAHs and TPH at OU 1, with the highest concentrations from the 1990 and 1992 data listed. The following summary will focus largely on CAHs present in groundwater at OU 1.

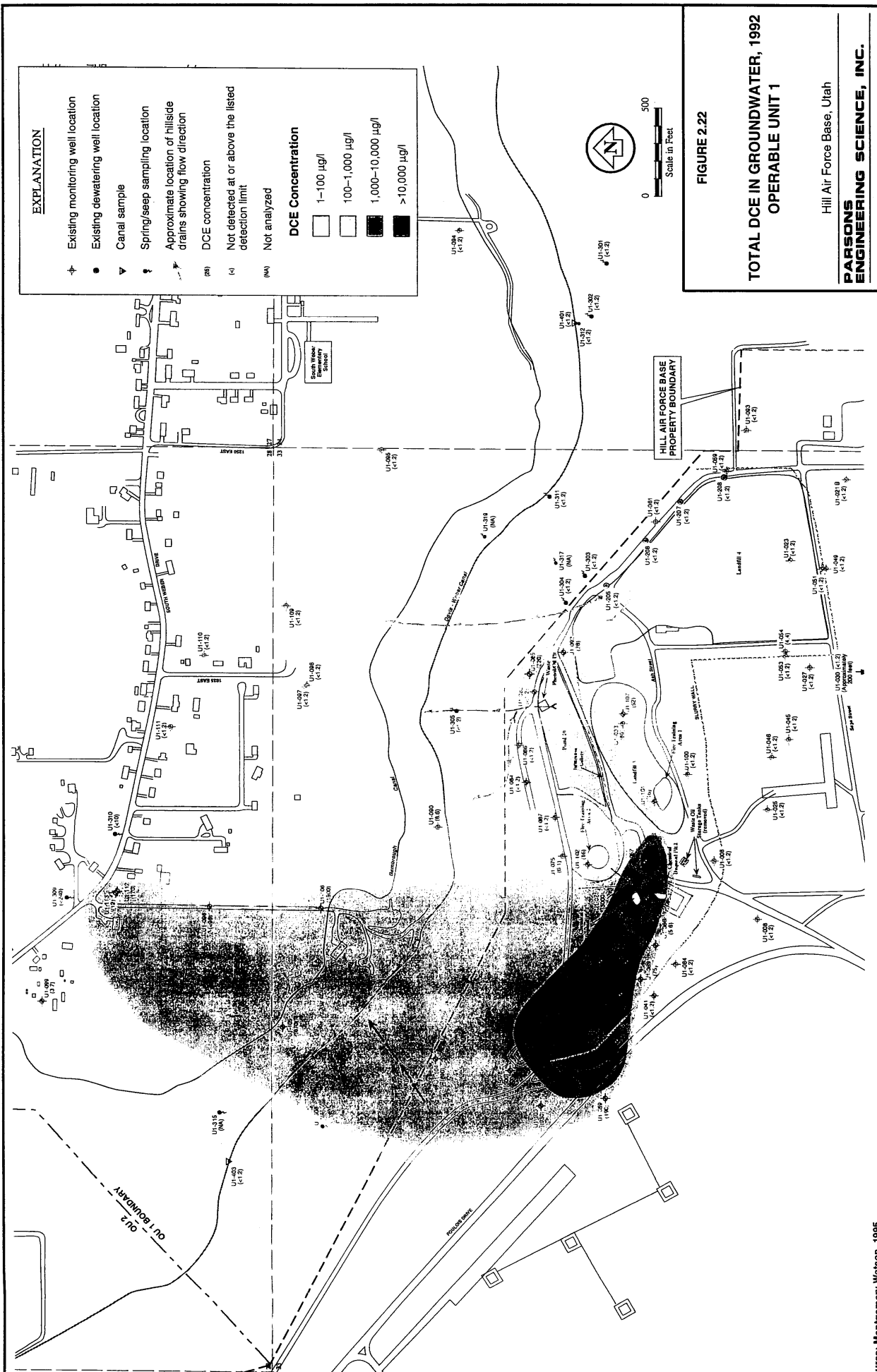
TPH compounds (quantified as either gasoline or jet fuel) were detected in many of the on-Base wells in the vicinity of the source areas and immediately west of the LNAPL body (Figure 2.20). The presence of these compounds is worth noting as an indicator of areas in which biodegradation of fuel hydrocarbons may be occurring and in which conditions for biodegradation of CAHs via cometabolism or reductive dehalogenation may therefore be more favorable.

The compound detected in the greatest concentrations and with the widest distribution is 1,2-DCE. Figures 2.21, 2.22, and 2.23 show the extent and concentrations of 1,2-DCE in groundwater in 1990, 1992, and 1994, respectively. Figure 2.24 shows the distribution of 1,2-DCE in the shallow and deep portions of the shallow aquifer at OU 1. In general, the areas with highest 1,2-DCE concentrations [up to 42,000 micrograms per liter ($\mu\text{g/L}$)] are beneath or in the vicinity of the LNAPL body. 1,2-DCE concentrations are generally lower in the off-Base portion of the plume, with maximum off-Base concentrations as high as 1,500 $\mu\text{g/L}$. From 1990 to 1994, the plume appears to grow, but this appears to be a result of the continued collection of data from new locations. It is therefore not clear if the plume is stable, shrinking, or growing. However, 1,2-DCE concentrations in the vicinity of the source area decreased between 1990 and 1994. As indicated on Figure 2.24, 1,2-DCE has been detected in a few deeper wells (screened in the silty clay unit beneath the on-base part of the plume), but at concentrations much lower than those observed in shallower wells.





Source: Montgomery Watson, 1995.



Source: Montgomery Watson, 1995.

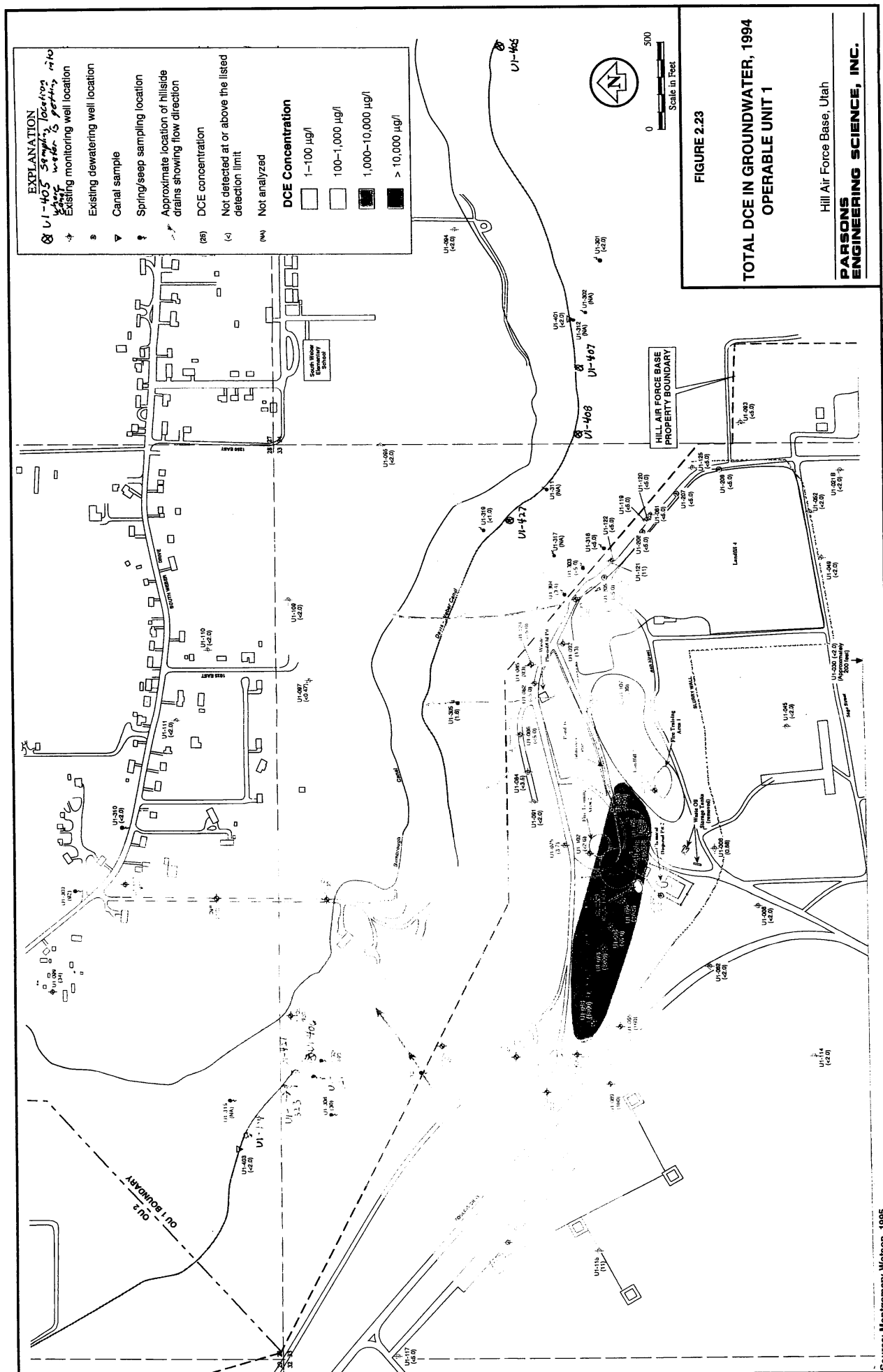


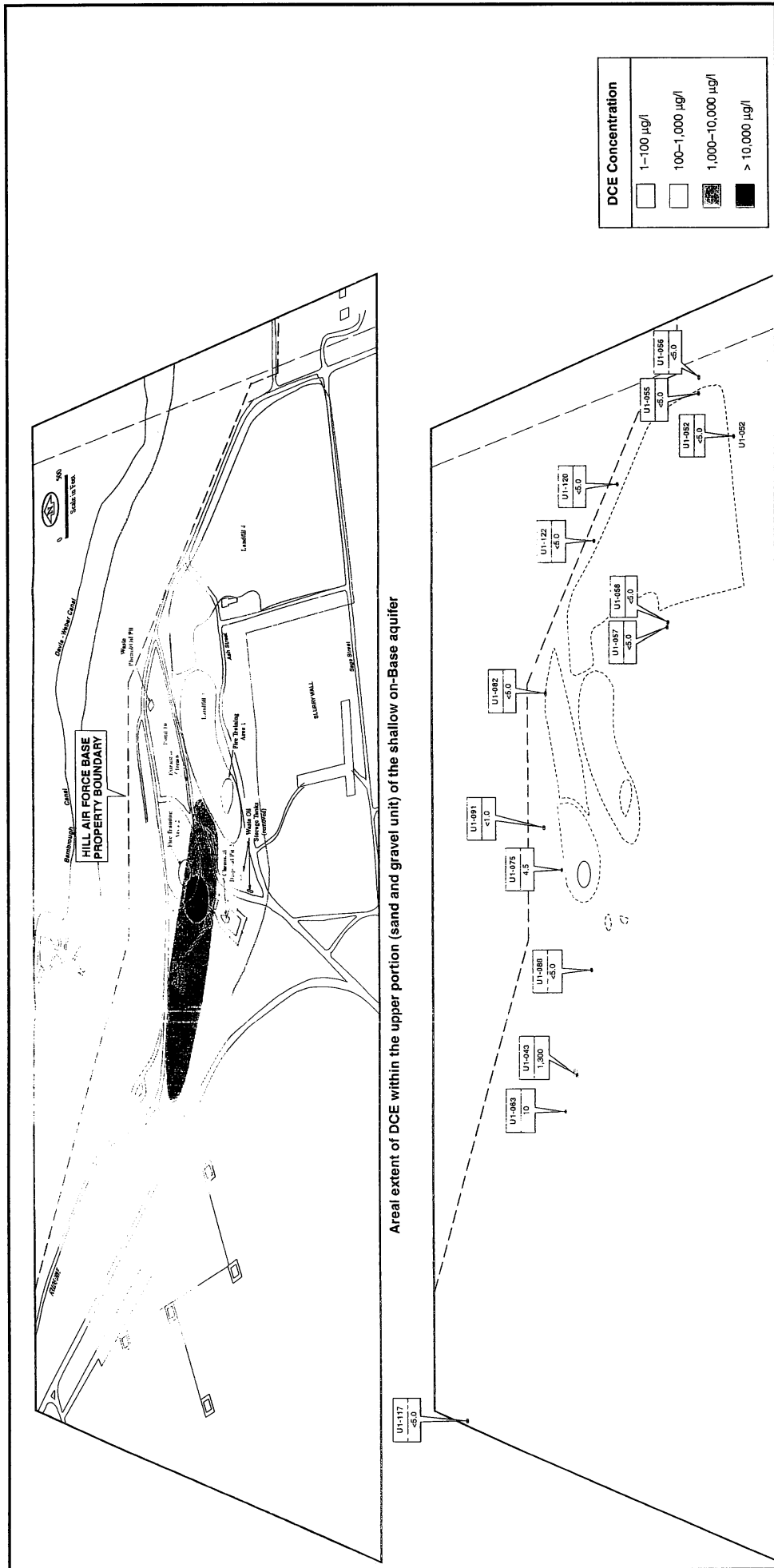
FIGURE 2.23

TOTAL DCE IN GROUNDWATER, 1994

OPERABLE UNIT 1

Hill Air Force Base, Utah

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Areal extent of DCE within the upper portion (sand and gravel unit) of the shallow on-base aquifer

Monitoring wells screened within the deeper portion (silty clay unit) of the shallow on-base aquifer

Source: Montgomery Watson, 1995.

It is not readily apparent what subsurface features are controlling DCE migration. There may be preferential flow paths, such as:

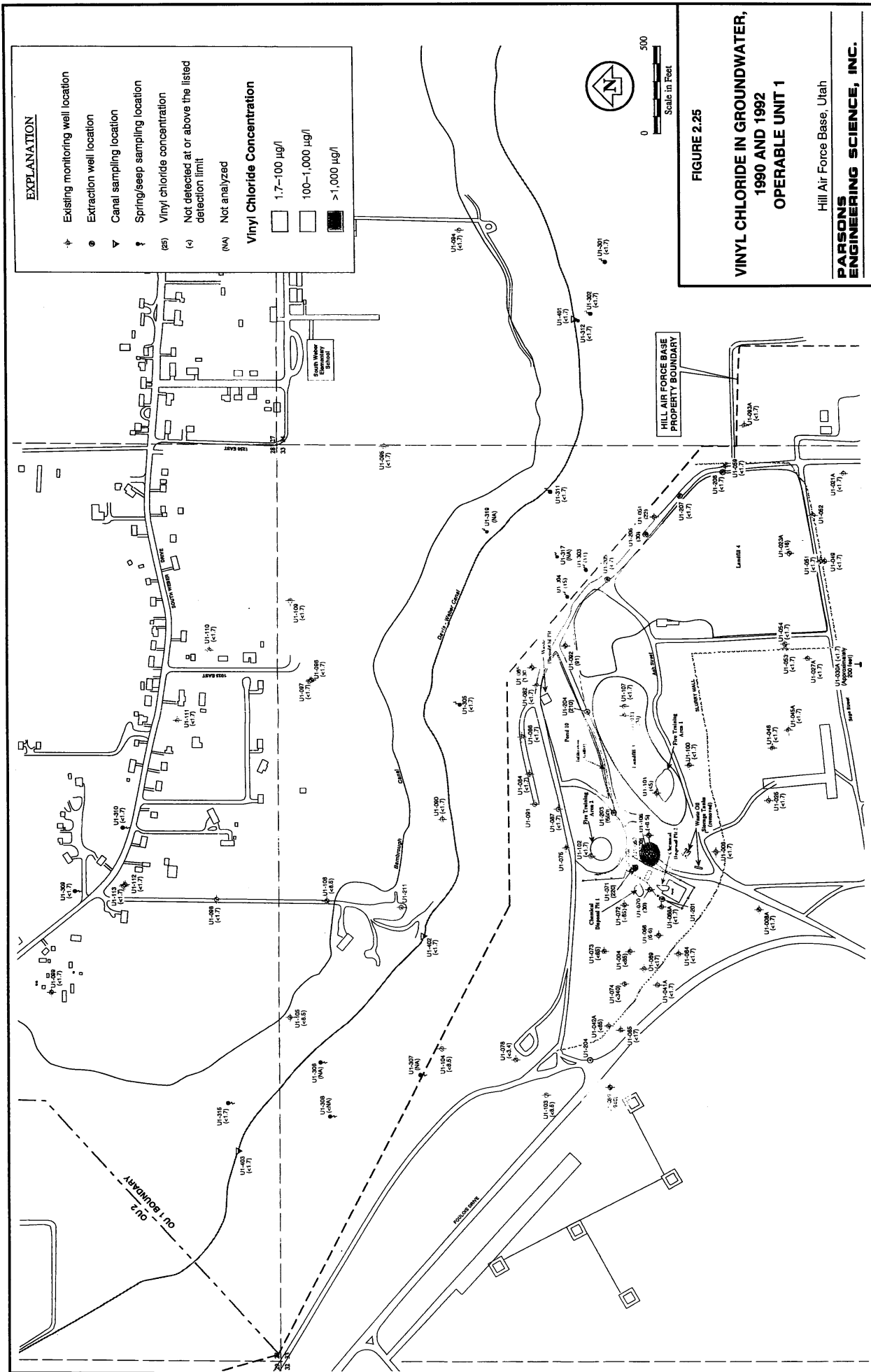
- A sand-and-gravel-filled paleochannel incised in the clay layer that may induce preferential groundwater flow in the western portion of OU 1;
- High-permeability landslide rubble/failure planes on the hillside downgradient of the CDPs; and/or
- Hillside drains, mainly in the western portion of OU 1.

The configuration of the LNAPL body and the distribution of the multiple source areas also are likely to have influenced the formation and migration pathway of the 1,2-DCE plume, in that the locations of the sources control which pathways are immediately impacted by dissolved contaminant concentrations. The location of the LNAPL toward the western part of OU 1 may have allowed contaminants to more easily reach some pathway in that area.

Groundwater 1,2-DCE data available for the preparation of this work plan (partially presented in Appendix A and on Figures 2.21 through 2.24) do not consistently include a breakdown of 1,2-DCE concentrations into *cis*-1,2-DCE and *trans*-1,2-DCE concentrations. *cis*-1,2-DCE is the most common DCE isomer produced during biodegradation of TCE. Some of the available data show greater *cis*-1,2-DCE than *trans*-1,2-DCE concentrations, but these data are inconclusive. Soil gas sampling results discussed in Section 2.1.3.1 suggest greater *cis*-1,2-DCE concentrations are present in the vapor phase at OU 1. However, this is not necessarily representative of dissolved DCE concentrations.

Of the other CAHs detected in site groundwater, only PCE was detected in one of the LNAPL samples for which data are presented in Appendix A; TCE was not detected in either sample. PCE and TCE concentrations were highest in the on-Base portion of the OU 1 CAH plume, with PCE concentrations as high as 58 µg/L and DCE concentrations as high as 2,300 µg/L detected in 1990 and 1992. At the same time, TCE concentrations up to 28 µg/L were detected in the off-Base part of the CAH plume, and PCE was not detected in the same area (Figure 2.20). However, the off-base extent of TCE was smaller than that of 1,2-DCE.

VC, a daughter product of PCE, TCE, and DCE biodegradation, was detected in the on-Base portion of the plume during the RI. Figures 2.25 and 2.26 show the distribution of VC in 1990 - 1992 and 1994, respectively. According to the LNAPL sample results in Appendix A, no VC was detected in the LNAPL. Therefore, the presence of VC suggests that some biologically mediated reductive dehalogenation of CAHs is occurring in the vicinity of the on-Base portion of the plume. No VC has been detected in the downgradient off-Base wells. The maximum VC concentration detected in 1990 and 1992 was 2,400 µg/L, detected in well U1-067, located just east the CDPs.



EXPLANATION

UT-085 MONITORING WELL

25 VINYL CHLORIDE
ISCONCENTRATION
CONTOUR (ug/l)

CHEMICAL DISPOSAL PITS

UT-319 SPRING / SEEP

VINYL CHLORIDE CONCENTRATIONS

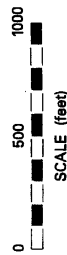
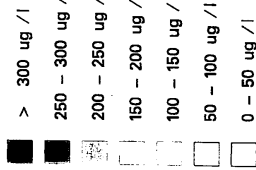
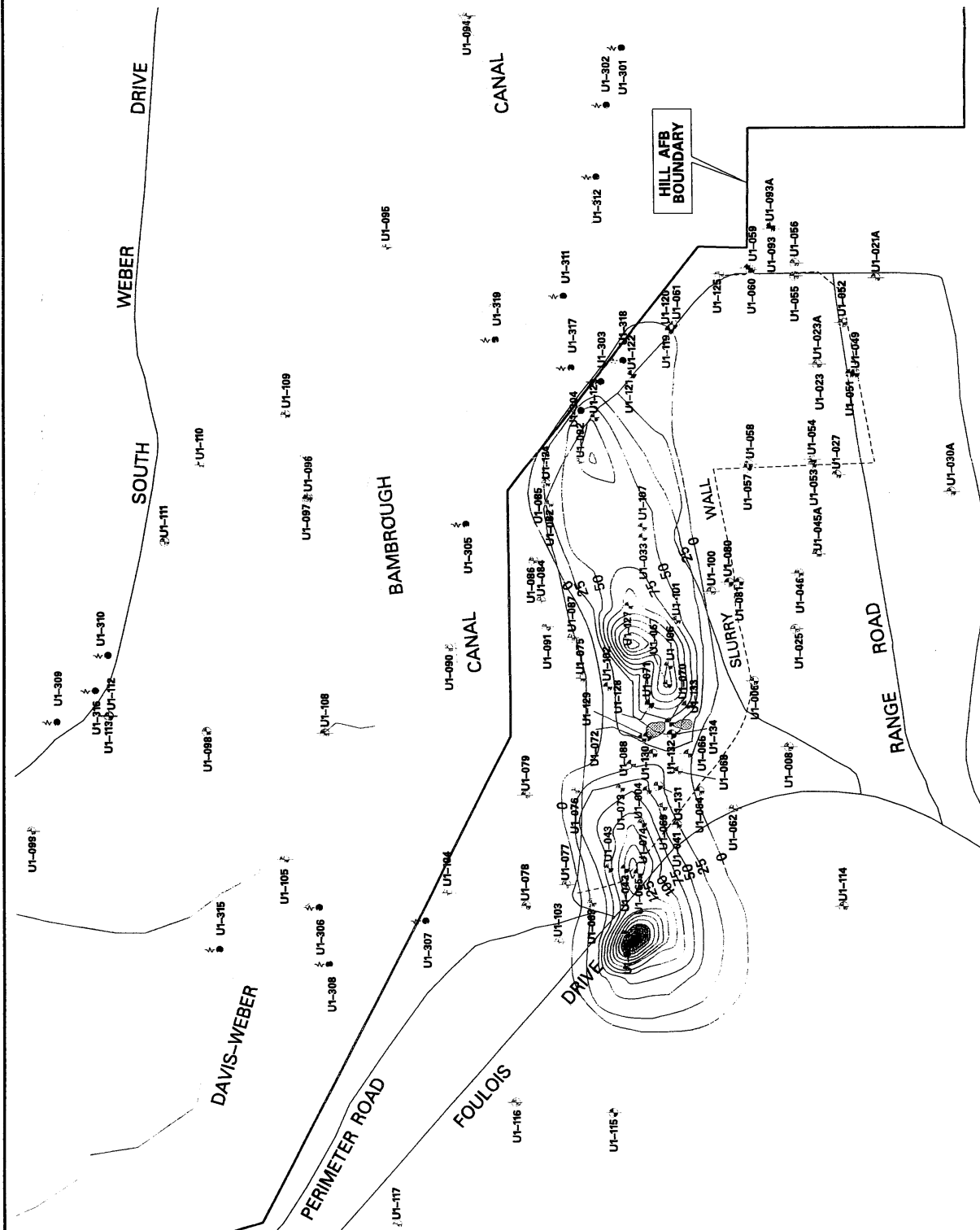


FIGURE 2.26

VINYL CHLORIDE IN GROUNDWATER, MAY 1994 OPERABLE UNIT 1

Hill Air Force Base, Utah

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Another CAH, 1,1,1-TCA, was also detected in the LNAPL and in the groundwater at OU 1. In 1990 and 1992, 1,1,1-TCA concentrations in on-Base groundwater were as high as 2,000 µg/L, and it was also detected in one off-Base well (U1-108) at a concentration of 14 µg/L (Figure 2.20). In addition to 1,1,1-TCA, concentrations of 1,1-DCA were also detected. This compound is a daughter product of anaerobic biodegradation of TCA, and was not detected in the LNAPL samples. In general, 1,1-DCA was detected in more wells than 1,1,1-TCA and was also detected off-Base in well U1-108.

Several springs and seeps discharge along the face of the hillside north of the OU 1 source areas, in the vicinity of the canals that follow the contours of the hillside, and along South Weber Drive (Figure 2.19). Data from these sampling points are also presented on Figures 2.20 through 2.26. These data show that groundwater containing detectable concentrations of 1,2-DCE, VC, and 1,1-DCA has discharged to the ground surface at least at locations U1-303, U1-304, U1-305, U1-306, U1-308, and U1-309. In general, these compounds are discharging to the surface in the area immediately north and northeast of Landfill 3, Pond 10, and the WPOP, and within the area of the dissolved 1,2-DCE plume extending north of the base and into South Weber.

TCE and 1,2-DCE data from two of the springs (U1-308 and U1-309) are presented on Table 2.3. U1-308 is in the central portion of the CAH plume that extends northward from the western portion of OU 1, and U1-309 is near the downgradient edge of the same plume. Concentrations of 1,2-DCE in U1-308 increased from less than 6 µg/L in 1987 to about 30 µg/L in 1993, but were relatively stable in 1993 and 1994. Over the same time frame, TCE concentrations at the same location decreased from about 20 µg/L to less than 0.5 µg/L. At U1-309, 1,2-DCE concentrations were generally stable from 1990 to 1994, as were TCE concentrations. This suggests the plume may be stable or nearly so, because contaminant concentrations are not increasing at the downgradient end of the plume and have only increased slightly in the central portion of the plume.

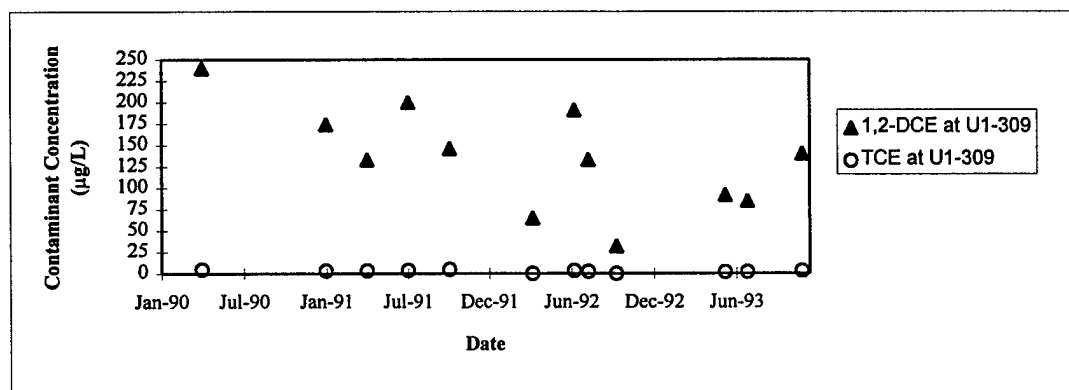
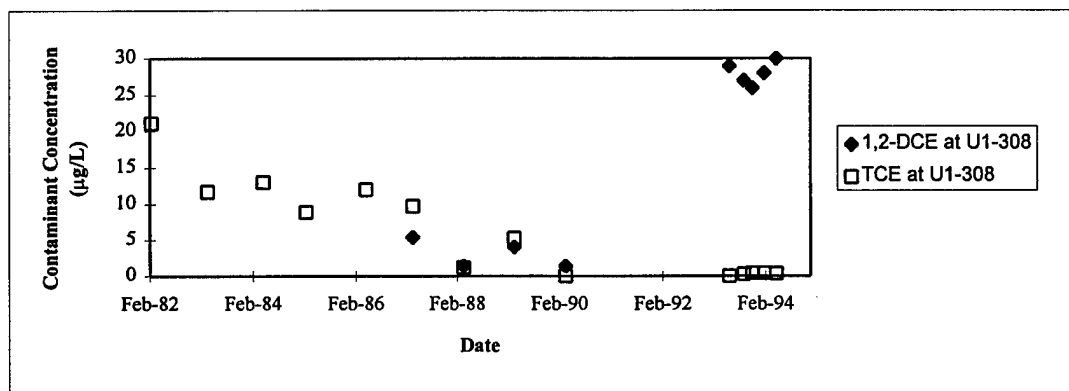
2.1.4 Groundwater Geochemistry

Stiff diagrams of the groundwater graphically showing mass balance of cations to anions are provided on Figure 2.27. The Stiff diagrams suggest that shallow groundwater beneath the on-Base source area is calcium-bicarbonate water, while groundwater obtained from deeper wells (screened in the silty clay) is generally sodium-bicarbonate, with lower concentrations of total dissolved solids (TDS). The groundwater from the off-Base wells seems to be higher in TDS than groundwater obtained from the on-Base shallow wells, and is generally calcium-bicarbonate. The inorganic water chemistry and water quality parameters from these monitoring wells are provided in Appendix A.

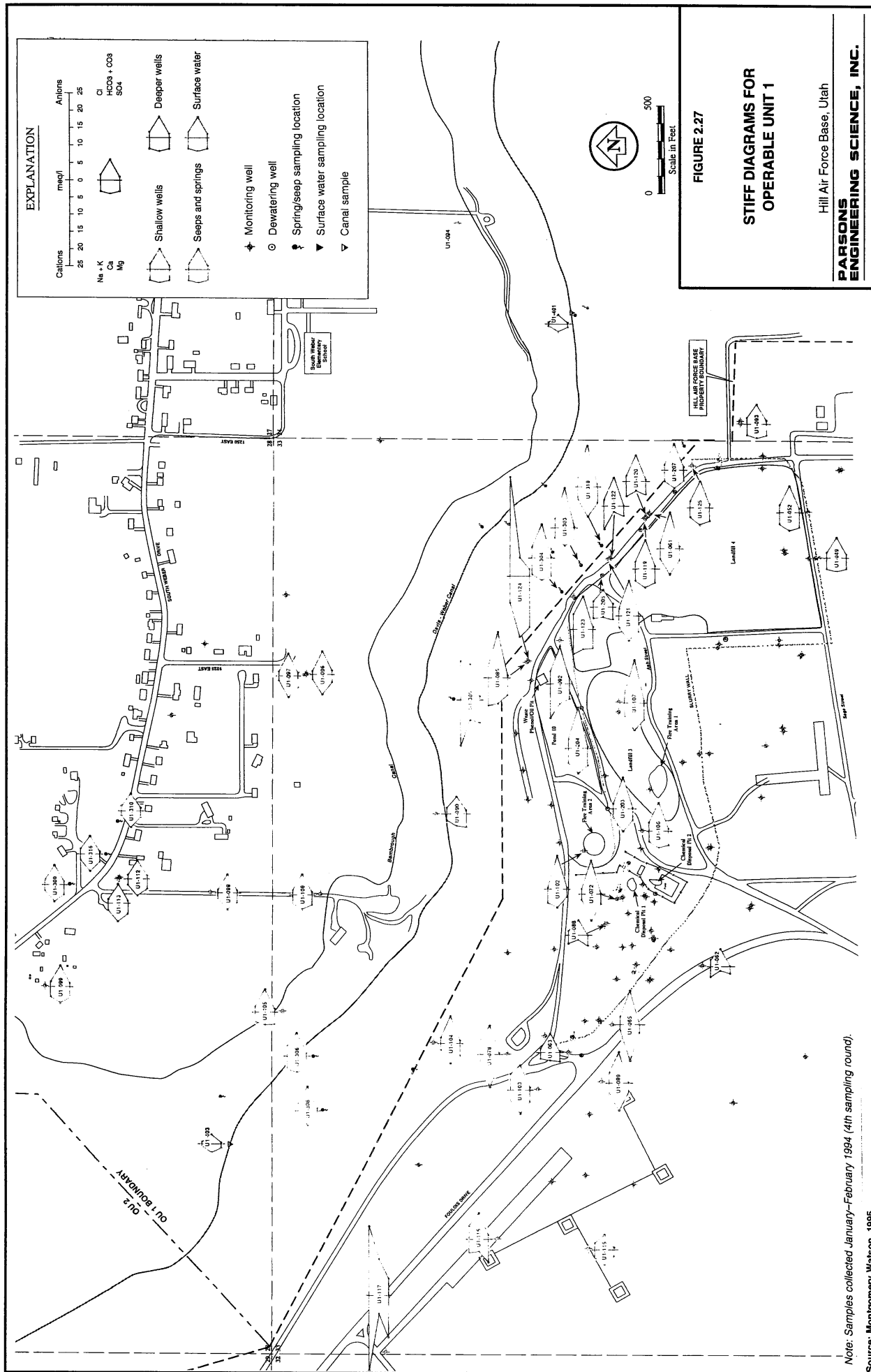
Dissolved oxygen (DO) concentrations, oxidation/reduction potential (ORP, also known as redox potential), temperature, pH, various cation levels, and anion levels in selected wells have been measured periodically in the field since May 1993 (Appendix A). DO results from May 1994 are presented in Figure 2.28. DO concentrations were

TABLE 2.3
SUMMARY OF TCE AND 1,2-DCE DATA FROM SPRINGS
IN THE WESTERN PORTION OF THE OU 1 AREA
Hill Air Force Base, Utah

Spring U1-308			Spring U1-309		
Date	1,2-DCE (µg/L)	TCE (µg/L)	Date	1,2-DCE (µg/L)	TCE (µg/L)
3/1/82	NA	21.1	4/5/90	240	4.7
4/1/83	NA	11.7	1/1/91	174	3.2
5/1/84	NA	13	4/1/91	133	3.3
3/1/85	NA	8.9	7/1/91	200	3.9
5/1/86	NA	12	10/1/91	146	5.0
4/1/87	5.4	9.7	4/1/92	65	<5
4/1/88	1.4	1.2	7/1/92	191	3.4
4/1/89	4.1	5.3	8/1/92	133	2.2
4/1/90	1.4	<0.5	10/1/92	32	ND
6/3/93	29	<5	5/26/93	92	1.8
9/16/93	27	0.28	7/14/93	85	1.9
11/15/93	26	0.38	11/11/93	140	2.9
2/7/94	28	0.38	1/27/94	130	2.6
5/5/94	30	0.34			



Source: Montgomery Watson, 1995.



Note: Samples collected January-February 1994 (4th sampling round).
Source: Montgomery Watson, 1995.

EXPLANATION

• U1-095 MONITORING WELL

5 - DISSOLVED OXYGEN CONCENTRATION CONTOUR (mg/l)

CHEMICAL DISPOSAL PITS

• U1-319 SPRING / SEEP

DISSOLVED OXYGEN CONCENTRATIONS

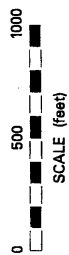
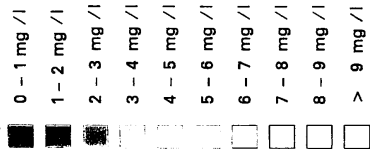
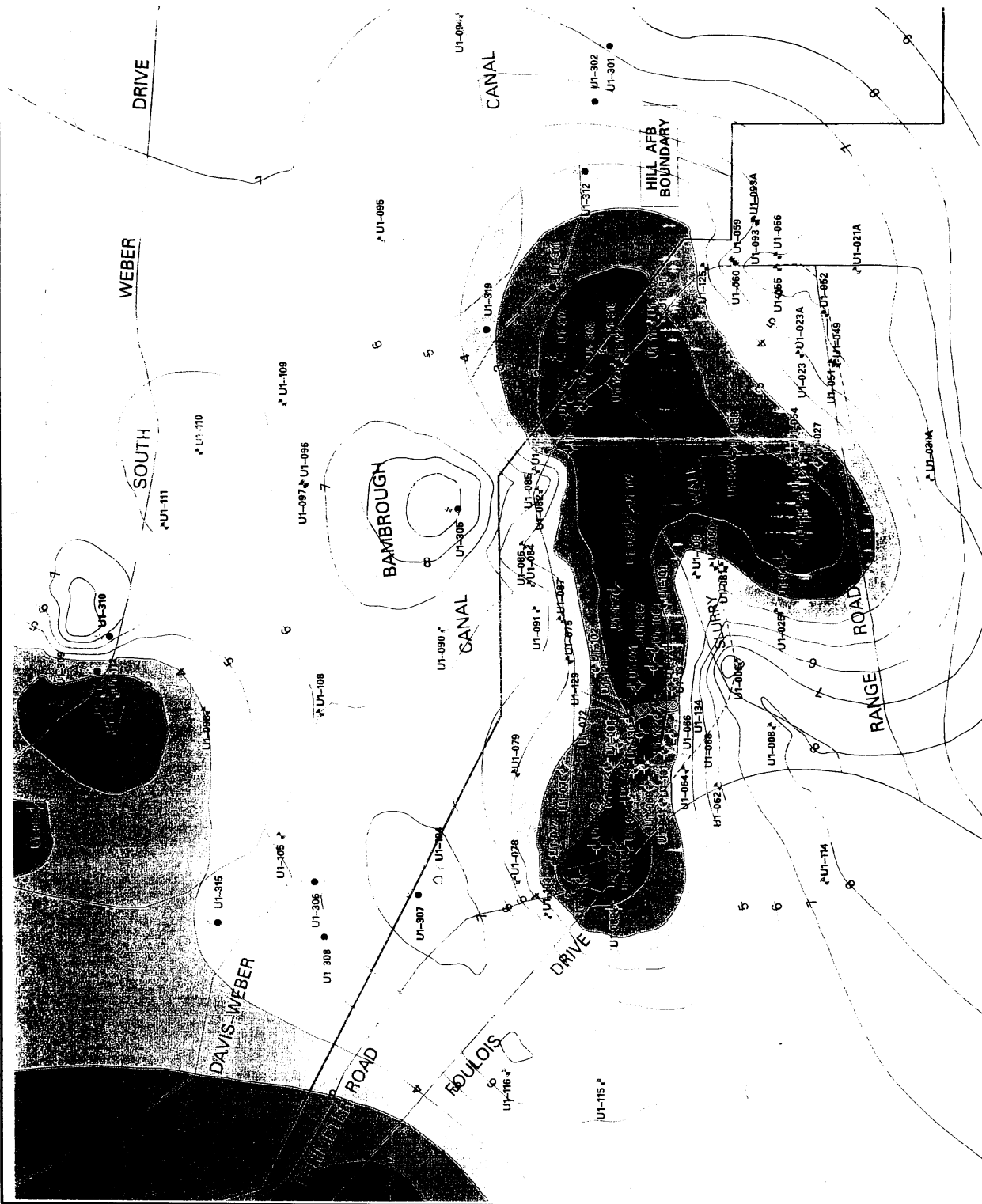


FIGURE 2.28

DISSOLVED OXYGEN
IN GROUNDWATER,
MAY 1994
OPERABLE UNIT 1

Hill Air Force Base, Utah

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lower within the on-Base portion of the CAH plume, generally below 4 milligrams per liter (mg/L) and in many places less than 1 mg/L. This implies oxygen depletion caused by aerobic metabolism of fuel hydrocarbon compounds. Limited sulfate and nitrate concentration data presented in Appendix A suggest that sulfate and nitrate concentrations are also depleted in the area where DO concentrations are depleted and iron concentrations are enriched, further indicating that biodegradation using fuel hydrocarbons as a substrate is ongoing in the on-Base area.

Total iron data for groundwater are also available and are plotted on Figure 2.29. In general, iron concentrations are elevated in the vicinity of the source area of the OU 1 contaminant plume, including some concentrations over 10,000 µg/L (10 mg/L). While these data do not differentiate between iron (II) and iron (III) concentrations, Montgomery Watson (1995) showed that for the redox and pH conditions in the source area, iron (II) (ferrous iron) is the stable form of soluble iron. The presence of soluble iron (II) is a solid indicator of biodegradation.

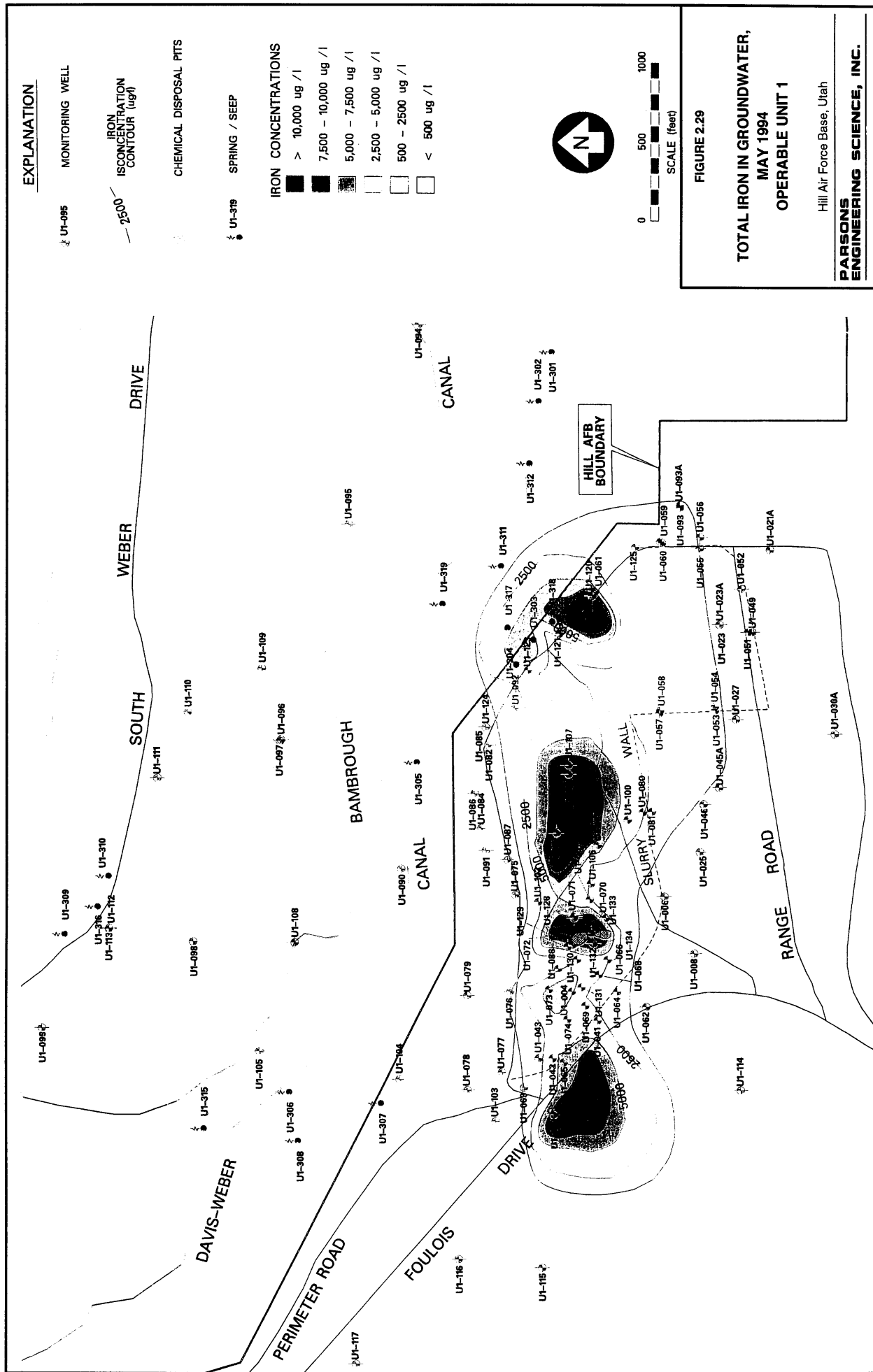
ORPs (i.e., redox potentials) were reduced (more negative) in the center of the on-Base CAH plume, ranging from less than -125 to about 75 millivolts (mV) in May 1994, while background potentials were over 175 mV (Figure 2.30). This is consistent with the other geochemical data that indicate that microbial processes are consuming DO and other electron acceptors and creating reducing conditions in the source area that are favorable for reductive dehalogenation of CAHs. Montgomery Watson (1995) showed half-reaction reduction potentials for CAHs of interest relative to measured ORPs (Figure 2.31). These data suggest that on-Base ORPs are locally low enough that reductive dehalogenation can proceed.

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual model is a three-dimensional representation of a hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A site-specific conceptual model is developed to provide an understanding of the mechanisms controlling contaminant fate and transport and to identify additional data requirements. The model describes known and suspected sources of contamination, types of contamination, affected media, and contaminant migration pathways. The model also provides a foundation for formulating decisions regarding additional data collection and potential remedial actions. The conceptual model for OU 1 will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling chlorinated solvent and petroleum hydrocarbon attenuation using groundwater flow and solute transport models.

Successful conceptual model development involves:

- Defining the problem to be solved;
- Integrating available data, including
 - Local geologic and topographic data,



EXPLANATION

UT-095 MONITORING WELL

100 REDOX POTENTIAL
ISCONCENTRATION
CONTOUR (millivolts)

CHEMICAL DISPOSAL PITS

UT-319 SPRING / SEEP

REDOX POTENTIAL

< -125 millivolts
-125 - -75 millivolts
-75 - -25 millivolts
-25 - 25 millivolts
25 - 75 millivolts
75 - 125 millivolts
125 - 175 millivolts
175 - 225 millivolts
> 225 millivolts

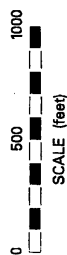
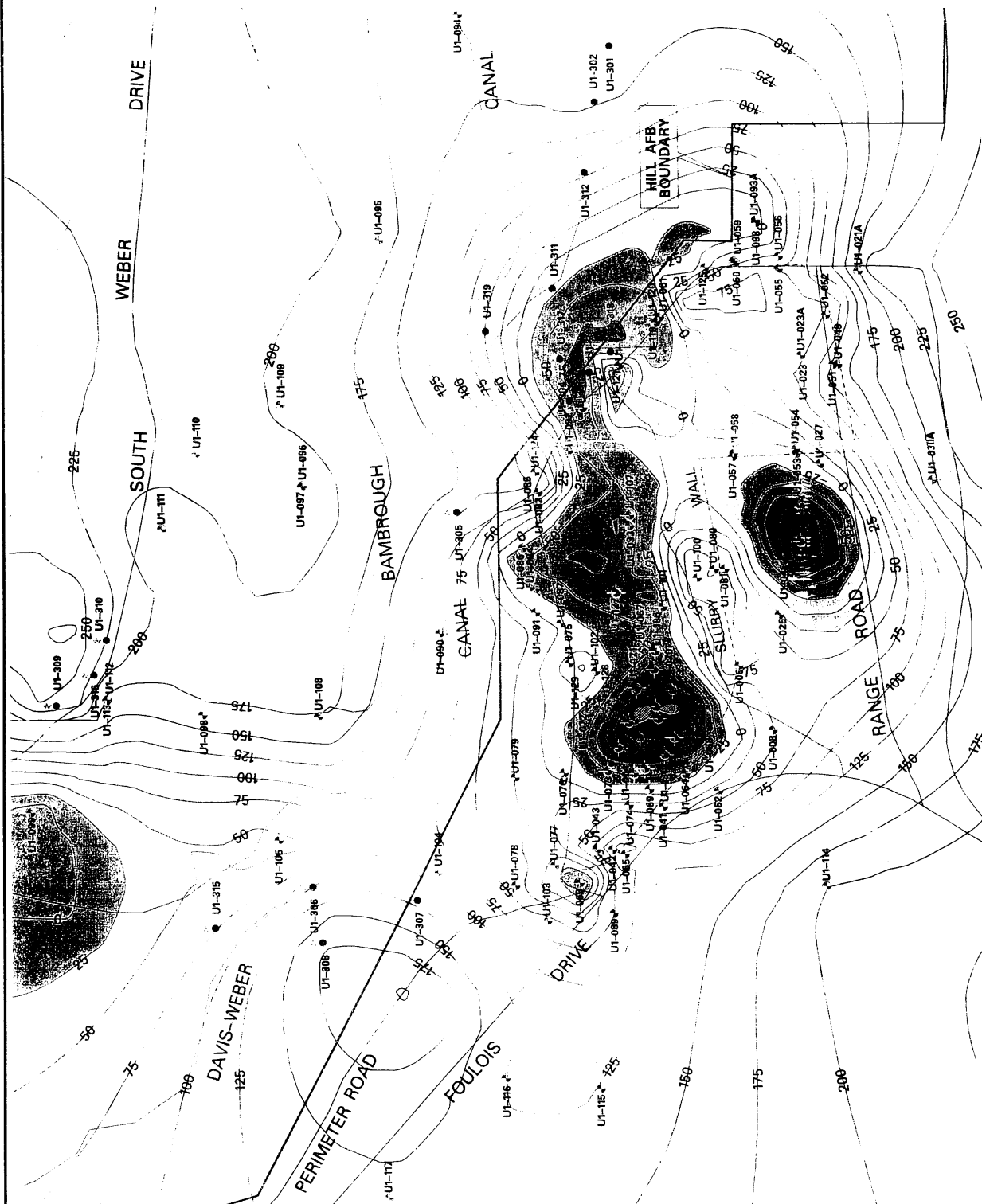


FIGURE 2.30

REDOX POTENTIAL
OF GROUNDWATER,
MAY 1994
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Source: Montgomery Watson, 1995.

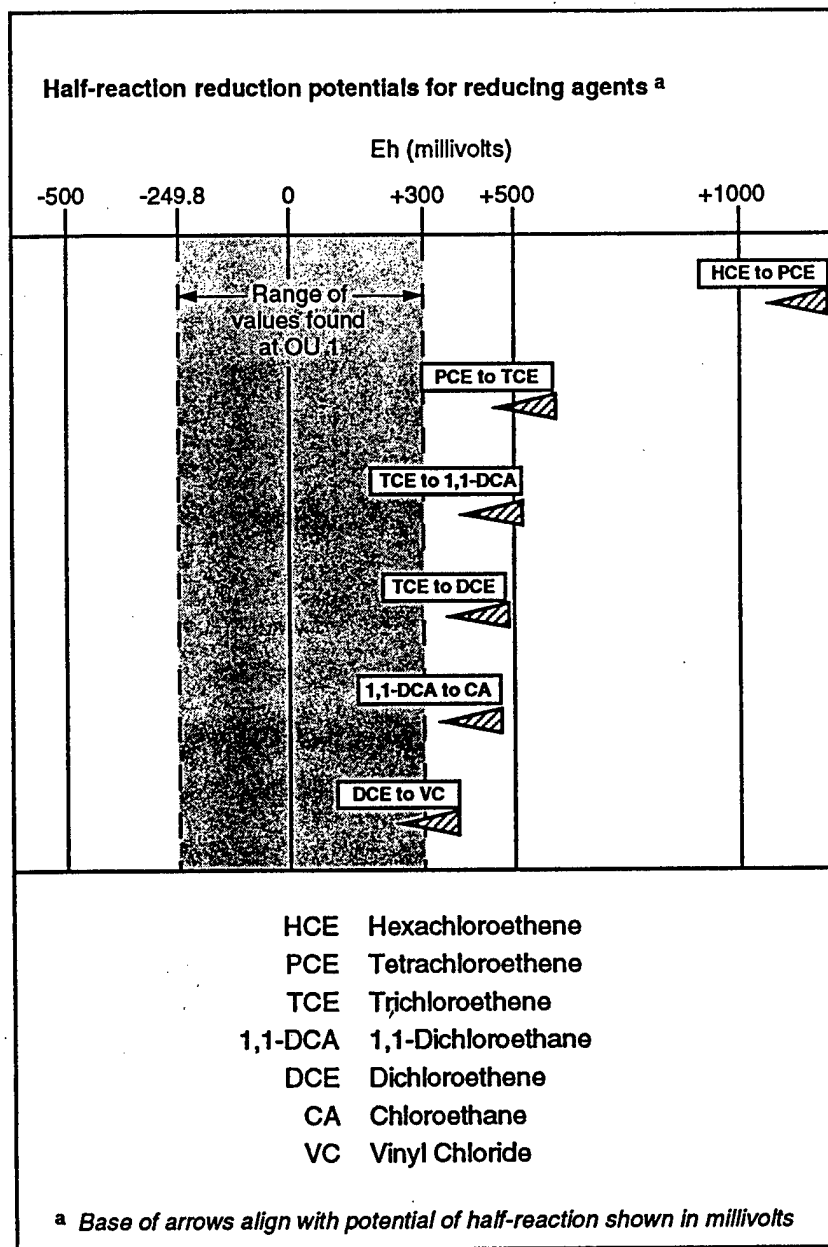


FIGURE 2.31

**HALF-REACTION
REDUCTION POTENTIALS
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- Hydraulic data,
- Site stratigraphic data, and
- Contaminant concentration and distribution data;
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant migration pathways;
- Identifying potential receptors and exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Solute Transport Models

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and human and ecological receptor exposure pathway completion. Groundwater flow and solute transport models have proven useful for predicting plume migration and contaminant attenuation by natural biodegradation. Analytical and numerical models are available for modeling the fate and transport of CAHs under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models derived from advection-dispersion equations [e.g., models such as those presented by Wexler (1992) and van Genuchten and Alves (1982)] may be useful. However, because CAH biodegradation may be the result of different processes in different locations, it may be necessary to use a numerical model to incorporate spatial variability in contaminant decay rates.

An accurate estimate of the potential for natural biodegradation of chlorinated compounds in groundwater is important to consider when determining whether groundwater contamination presents a substantial threat to human health and/or the environment, and when deciding what type of remedial alternative will be most cost effective in eliminating or abating these threats. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (Lee, 1988; McCarty *et al.*, 1992). The following section discusses the biodegradation of CAHs.

2.2.2 Biodegradation of CAHs

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Miller and Guengerich, 1982; Wilson and Wilson, 1985; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a and 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*,

1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or low-molecular-weight CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds also can provide evidence on the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.2.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 2.32 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Chlorinated ethanes follow a similar pathway, from TCA to 1,1-DCA and then chloroethane, which can further be transformed to chloroethane (CA) (Bouwer, 1994). CA is relatively stable biologically, but it may transform abiotically to ethanol and chloride. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

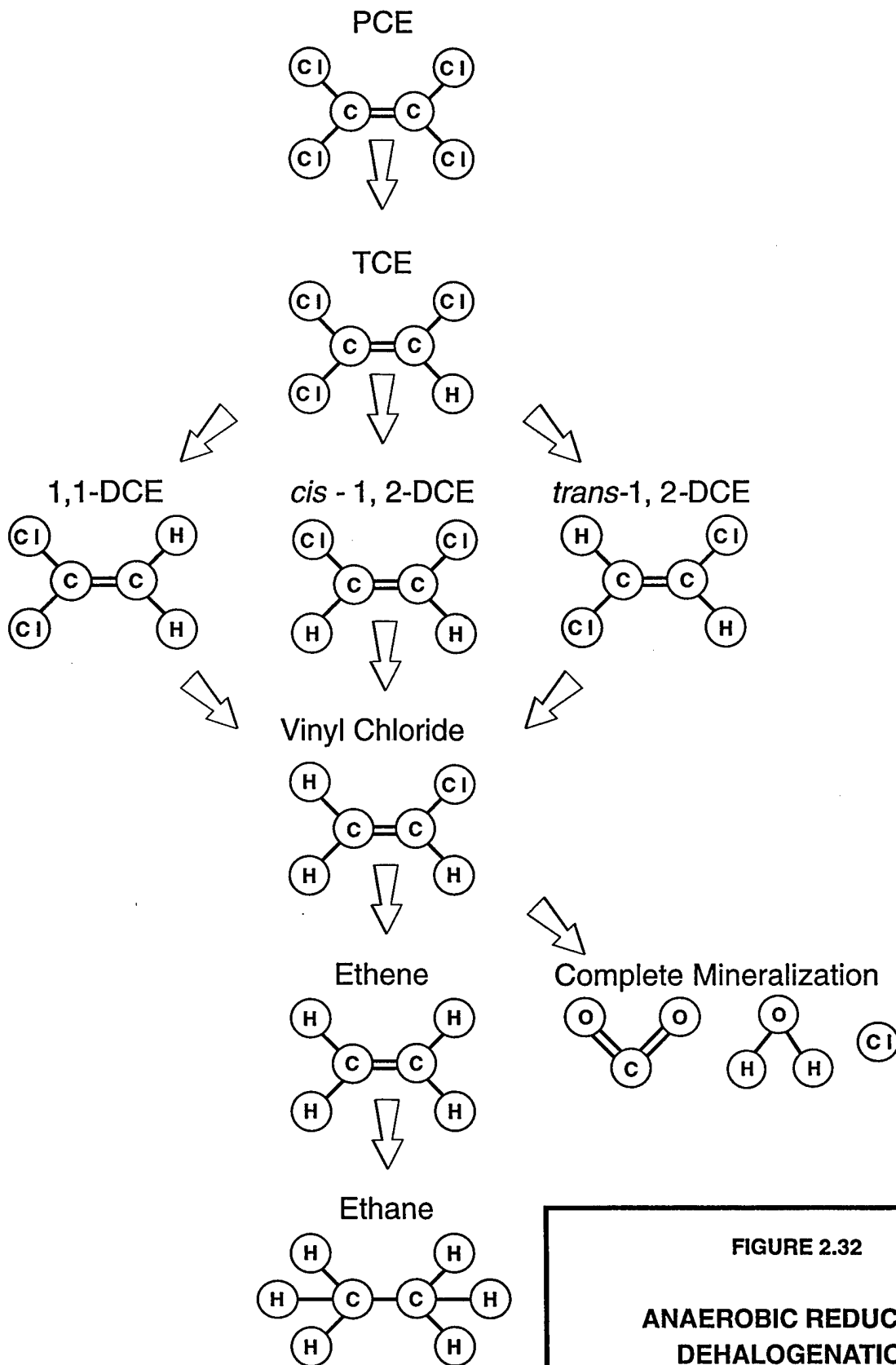


FIGURE 2.32

**ANAEROBIC REDUCTIVE
DEHALOGENATION**

Hill Air Force Base, Utah

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Reductive dehalogenation affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation. Reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons.

2.2.2.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable (ferric) iron. Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and the presence of chloromethane.

2.2.2.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather, the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. Aerobic biodegradation pathways for chlorinated ethenes are illustrated in Figure 2.33. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dehalogenation decreases.

In the cometabolic process, TCE is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (BTEX or other organic carbon sources) may limit cometabolism of CAHs.

2.2.2.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

2.2.2.4.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dehalogenation. When evaluating intrinsic remediation of a plume exhibiting type 1 behavior the following questions must be answered:

- 1) Does electron donor supply exceed demand (i.e., is the electron donor supply adequate)?
- 2) Will the CAH plume "strangle" before it "starves" [i.e., will it run out of CAHs (electron acceptors) before it runs out of primary substrate (electron donors)]?
- 3) What is the role of competing electron acceptors?
- 4) Is VC oxidized, or is it reduced?

2.2.2.4.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dehalogenation (i.e., the primary substrate for microorganism growth is native organic carbon). When

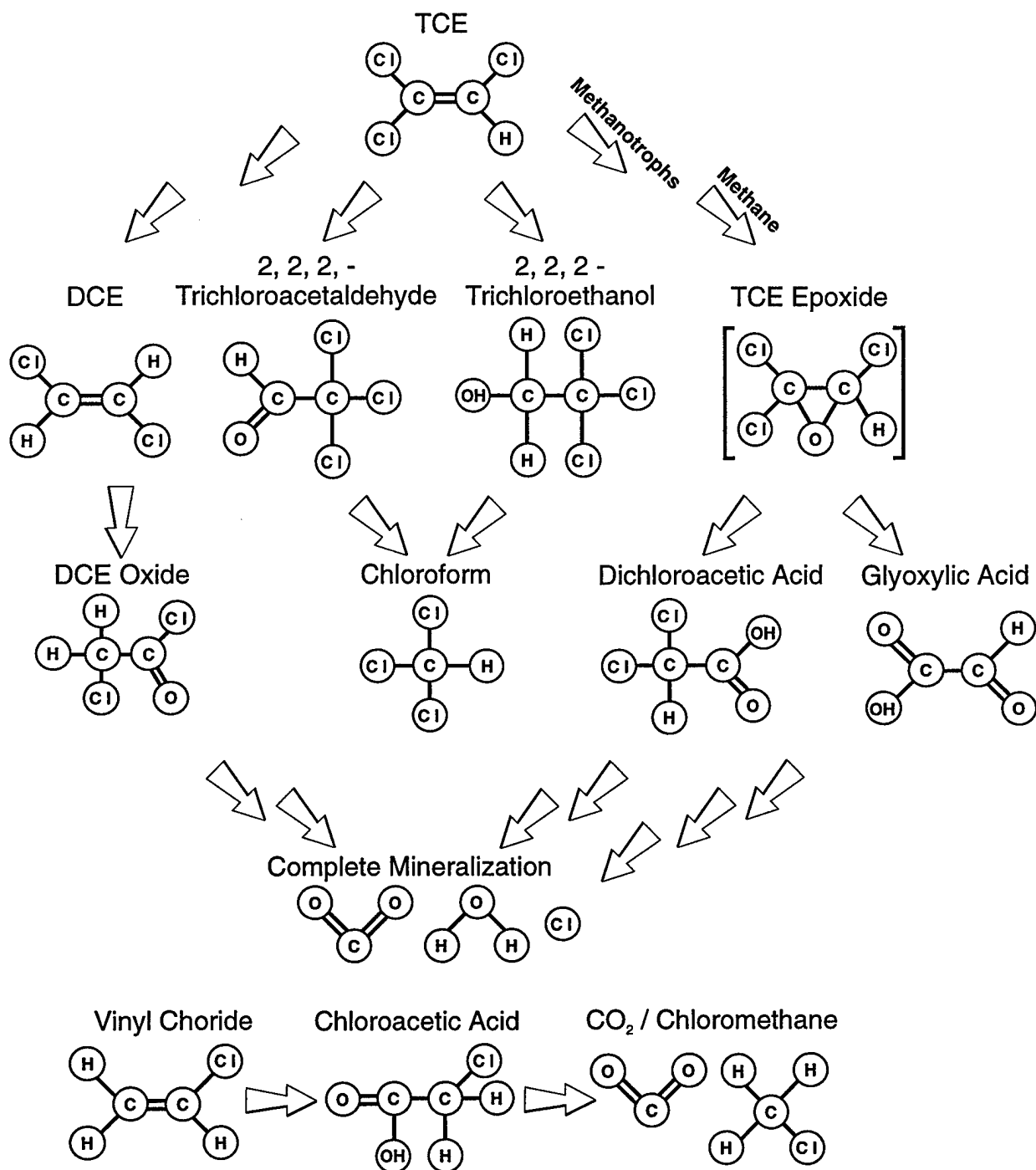


FIGURE 2.33

AEROBIC DEGRADATION

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Denver, Colorado

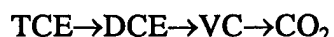
evaluating intrinsic remediation of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

2.2.2.4.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low native and/or anthropogenic carbon concentrations, and DO concentrations that are greater than 1.0 mg/L. Under these conditions the plume is aerobic, and reductive dehalogenation will not occur. Thus there is no reductive dehalogenation of PCE, TCE, and DCE. Biodegradation may proceed via the much slower process of cometabolism, but will be limited by the low concentrations of native or anthropogenic carbon. The most significant natural attenuation mechanisms for these compounds will be advection, dispersion, and sorption. However, VC could be oxidized under these conditions.

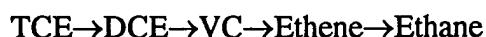
2.2.2.4.4 Mixed Behavior

As mentioned above, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1996) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dehalogenated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). VC is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.



In general, the TCE, DCE, and VC may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. VC is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dehalogenated (type 2 or 3 behavior). VC is reduced to ethene, which is further reduced to ethane. The following sequence of reactions occur in this type of plume.



In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate. This type of reductive dehalogenation is the described by Freedman and Gossett (1989).

2.2.2.4.5 Abiotic Transformations

In general, abiotic transformations of CAHs are not significant relative to other natural attenuation processes such as dispersion and sorption. However, 1,1,1-TCA

can be transformed abiotically to form 1,1-DCE (and ultimately VC) or acetic acid, although the process is relatively slow, with a half-life on the order of one year (Vogel *et al.*, 1987; Bouwer, 1994; Vogel 1994). Such processes can complicate the study of CAH transformation, particularly if conditions are such that the half-life of the abiotic process is similar to that of any ongoing biological processes.

2.2.3 Initial Conceptual Model

OU 1 geologic and hydrogeologic data were previously summarized (Montgomery Watson, 1995) to produce hydrogeologic cross-sections of the site. Cross-sections A-A' through E-E' (Figures 2.7 through 2.11) show that the site hydrogeology is relatively simple, with the base of the shallow aquifer system defined by the clay and silty clay unit. Figure 2.12 is a groundwater surface map prepared using 1994 groundwater elevation data (Montgomery Watson, 1995). Groundwater is present approximately 15 to 30 feet bgl in the sand and gravel and sandy silt deposits in the vicinity of OU 1, with the depth to groundwater decreasing in the off-Base area north of the Davis-Weber Canal. Groundwater flows generally to the north, with a northwesterly component. The deeper aquifers appear to be isolated from the shallow aquifer by the silt and clay confining unit; this is partially confirmed by sampling results suggesting that there is little downward migration of DCE into the confining unit (Figure 2.24). On the basis of the available data, the site will be modeled as an unconfined, sand to sandy silt aquifer. This conceptual hydrogeologic model will be modified as necessary as additional site hydrogeologic data become available.

CAHs, the chemicals of concern in groundwater at OU 1, will be the primary focus of this RNA demonstration because of their regulatory importance. CAHs are expected to leach from contaminated soils and LNAPL into the groundwater, and to migrate downgradient as a dissolved contaminant plume.

In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, and adsorption), these dissolved contaminants likely will be removed from the groundwater system by naturally occurring destructive attenuation mechanisms, such as biodegradation and abiotic degradation of TCA. Given available information, the CAH plume originating at the LNAPL smear zone appears to exhibit type 1 behavior, with anthropogenic organic carbon (i.e., petroleum hydrocarbons) utilized in the biodegradation reactions.

There is evidence suggesting favorable conditions for reductive dehalogenation of CAHs. The area in the western portion of the on-Base DCE plume displays relatively reducing conditions, with low DO concentrations (<2 mg/L) and ORPs (Figures 2.28 and 2.30). In addition, soluble iron concentrations are elevated, suggesting the formation of iron (II) due to biodegradation reactions (Figure 2.29). Also, the geochemical data presented in Appendix A show that some wells in the vicinity of the plume source area have depleted concentrations of sulfate and nitrate (alternate electron acceptors) relative to background concentrations.

While the available geochemical data suggest conditions are favorable for reductive dehalogenation of CAHs in the OU 1 source area, the CAH data also suggest that this process is taking place. The presence of VC in site groundwater is a good indicator, especially because no VC was reported in the LNAPL. Also, the presence of limited PCE and TCE concentrations relative to 1,2-DCE in the source area and downgradient is consistent with the occurrence of reductive dehalogenation. However, without the presence of VC, the latter data alone would not be useful. The presence of 1,1-DCA also is a good indicator of reductive dehalogenation, again because this compound was not reported to be present in the LNAPL samples.

It is also possible that some portions of the plume (especially off-Base) exhibit type 3 behavior, depending upon the concentrations and availability of natural organic carbon, DO, and nitrate. This will be further clarified with the results of the sampling for this demonstration. It is likely that some biodegradation of CAHs at the site is aerobic (especially downgradient from the source areas), but the available evidence is insufficient to reach any conclusion. As noted in Section 1.1, a bench-scale microcosm study using sediment and water samples collected at the site and radiolabeled *cis*-1,2-DCE may be undertaken to determine if the local microbial population is capable of directly oxidizing DCE to carbon dioxide and water. Again, this work is outside of the scope of Parsons ES's contract and would be performed by another entity, likely the USEPA NRMRL. VC concentrations are generally limited to the vicinity of the source area, suggesting that the downgradient aerobic conditions may also foster the biodegradation of VC in the off-Base portions of the plume.

Contaminant data from springs suggests that the plume may be stable, and also shows that discharge of contaminated groundwater to the surface is a potential exposure pathway as well as a potential mechanism for removal of CAH mass (e.g., due to volatilization and photooxidation when discharged).

The effects of these fate and transport processes on the dissolved groundwater plume will be further investigated using quantitative groundwater analytical data and solute-transport models. Data collection and analytical requirements are discussed in Section 3 of this work plan.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete the demonstration and to determine if natural attenuation of chlorinated solvents is occurring at OU 1, additional site-specific physical and chemical hydrogeologic data will be collected to supplement the available site data. Many of these measurements and analyses are the same as those commonly performed at hazardous waste sites; however, some of the measurements and analyses are collected specifically to assess the efficacy of RNA for CAH plumes.

Physical hydrogeologic characteristics to be determined include:

- Depth from measurement datum to the groundwater surface in site monitoring wells;
- Locations of potential groundwater recharge and discharge areas;
- Locations of downgradient wells and their uses;
- Hydraulic conductivity through slug tests and downhole flow meter tests, as required;
- Estimates of dispersivity, where possible;
- Stratigraphic analysis of subsurface media; and
- Groundwater temperature.

Chemical hydrogeologic characteristics to be determined include:

- DO concentrations;
- Specific conductance;
- pH;
- ORP;
- TOC; and

- Additional chemical analysis of groundwater, surface water (at springs), soil, and (if possible) LNAPL samples for the parameters listed in Table 3.1.

Physical hydrogeologic parameters will be measured to further refine the site conceptual model and to aid in assembling and calibrating the groundwater flow portion of a site-specific solute transport model.

In general, analyses will be made to allow an inference of which biodegradation processes are ongoing, as well as to provide information useful for transport modeling. Some inorganic groundwater chemical parameters [e.g., ferrous iron, DO, and sulfate] are measured to evaluate if there is any ongoing degradation of native (or anthropogenic) carbon, as discussed in Section 2.2.2. If such processes are ongoing, they may facilitate degradation of CAHs via the pathways discussed under Section 2.2.2. Chloride data can be used as an indicator of reductive dehalogenation, which would increase chloride concentrations in the plume interior. Carbon dioxide data may also indicate biodegradation, as it is the ultimate product of many of the reaction pathways indicated on Figures 2.32 and 2.33. ORP will be measured to help evaluate whether conditions are sufficiently reducing for reductive dehalogenation, as well as an indicator parameter during well purging (along with DO, temperature, pH, and conductivity). Methane, ethane and ethene will be measured for evidence of complete dehalogenation of CAHs, while VOC concentrations also can be used to further evaluate the ongoing processes, as discussed in Section 2.2.2. Soil analyses will be performed to gain information of the distribution and concentrations of organic carbon, which can affect sorption or act as an electron donor. Analysis of a LNAPL sample (if sufficient LNAPL is present) could provide additional information on CAH concentrations, especially which isomers of 1,2-DCE are present. Additional analyses not listed in Table 3.1 may be performed at the discretion of USEPA NRMRL scientists. Some of these potential analyses are listed in Appendix B.

To obtain these data, soil and groundwater samples will be collected and analyzed. The following sections describe the procedures that will be followed when collecting additional site-specific data. Procedures to be used to collect soil samples are described in Section 3.1. Procedures to be used for the installation of new monitoring points are described in Section 3.2. Procedures to be used to collect groundwater grab samples and to sample groundwater monitoring wells, springs, and newly installed groundwater monitoring points are described in Section 3.3. Sample handling procedures are described in Section 3.4, and procedures used to measure aquifer parameters (e.g., hydraulic conductivity) are described in Section 3.5. Microcosm studies are discussed in Section 3.6.

3.1 SOIL SAMPLING AND ANALYSIS

The following sections describe soil sampling locations, sample collection techniques, equipment decontamination procedures, site restoration, and management of investigation-derived waste materials.

TABLE 3.1
ANALYTICAL PROTOCOL FOR
GROUNDWATER AND SOIL SAMPLES
Hill Air Force Base, Utah

MATRIX Analyte	METHOD	FIELD (F) OR FIXED-BASE LABORATORY (L)
WATER		
Total Iron	Colorimetric, Hach Method 8008	F
Ferrous Iron (Fe ²⁺)	Colorimetric, Hach Method 8146	F
Ferric Iron (Fe ³⁺)	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034	F
Sulfate	Colorimetric, Hach Method 8051	F
Nitrate	Titrimetric, Hach Method 8039	F
Nitrite	Titrimetric, Hach Method 8507	F
ORP	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	USEPA method E150.1/SW9040, direct-reading meter	F
Conductivity	USEPA method E120.1/SW9050, direct-reading meter	F
Temperature	USEPA method E170.1, direct-reading meter	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Alkalinity (Carbonate [CO ₃ ²⁻] and Bicarbonate [HCO ₃ ⁻])	F = Titrimetric, Hach Method 8221 L = USEPA Method 310.1	F L
Nitrate + Nitrite	USEPA Method 353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP-147 ^{a/}	L
Dissolved Organic Carbon	RSKSOP-102	L
VOCs (BTEX, CAHs, chloroform, chloromethane)	RSKSOP-148	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Moisture	ASTM D-2216	L
VOCs (BTEX + CAHs)	RSKSOP-124, modified	L
LNAPL		
VOCs (BTEX + CAHs)	GC/MS, Direct Injection	L

^{a/} RSKSOP = Robert S. Kerr Laboratory (now NRMRL) Standard Operating Procedure.

NOTE: Additional analyses (as indicated in Appendix B) also may be performed at the discretion of Parsons ES and USEPA NRMRL personnel.

3.1.1 Soil Sampling Locations and Analyses

Soil samples will be collected at up to 10 locations at OU 1 (including where monitoring points are installed), as shown on Figure 3.1. Some soil sampling will be performed to acquire phreatic soil microcosms. Some samples also will be collected at monitoring point installation locations upgradient and downgradient from the plume for analysis of soil TOC content. Table 3.1 presents the analytical protocol for soil and groundwater samples, and Appendix B contains detailed information on the analyses and methods to be used during this sampling effort. Because of the number of wells present at the site and the soil characterization documented in the RI, soil sampling may be minimized, depending on working conditions at the site.

A minimum of two samples will be collected from each sampling location. One sample will be taken at the water table, and one will be taken beneath the water table. Given the amount of soil data already available, the main purpose of soil sampling for this work will be to determine aquifer matrix TOC concentrations and to collect samples for microcosm studies. Additional samples and sampling intervals may be selected at the discretion of the Parsons ES field scientist.

A portion of each sample will be used to estimate concentrations of VOCs in the soil headspace, while another portion of selected samples will be sent to the laboratory for analytical analysis. Each laboratory soil sample will be placed in an analyte-appropriate sample container and hand-delivered to the USEPA field laboratory personnel for analysis. If possible, at least two saturated soil samples from locations upgradient, crossgradient, or far downgradient from the contaminant source will be analyzed for TOC. Each headspace VOC screening sample will be placed in a sealed plastic bag or mason jar and allowed to sit for at least 5 minutes. VOC concentrations in the oil headspace will then be determined using an organic vapor meter (OVM) or a PID, and the results will be recorded in the field records by the Parsons ES field scientist.

3.1.2 Sample Collection Using the Geoprobe® System

Soil samples will be collected using a Geoprobe® system. Geoprobe® is a hydraulically powered percussion/probing machine capable of advancing sampling tools through unconsolidated soils. This system allows rapid collection of soil, soil gas, or groundwater samples at shallow depths while minimizing the generation of investigation-derived waste. Figure 3.2 is a diagram of the Geoprobe® system.

Soil samples will be collected using a probe-drive sampler. The probe-drive sampler serves as both the driving point and the sample collection device and is attached to the leading end of the probe rods. To collect a soil sample, the sampler is pushed or driven to the desired sampling depth, the drive point is retracted to open the sampling barrel, and the sampler is subsequently pushed into the undisturbed soils. The soil cores are retained within brass, stainless steel, or clear acetate liners inside the sampling barrel. The probe rods are then retracted, bringing the sampling device to the surface. The soil sample can then be extruded from the liners for lithologic logging, or

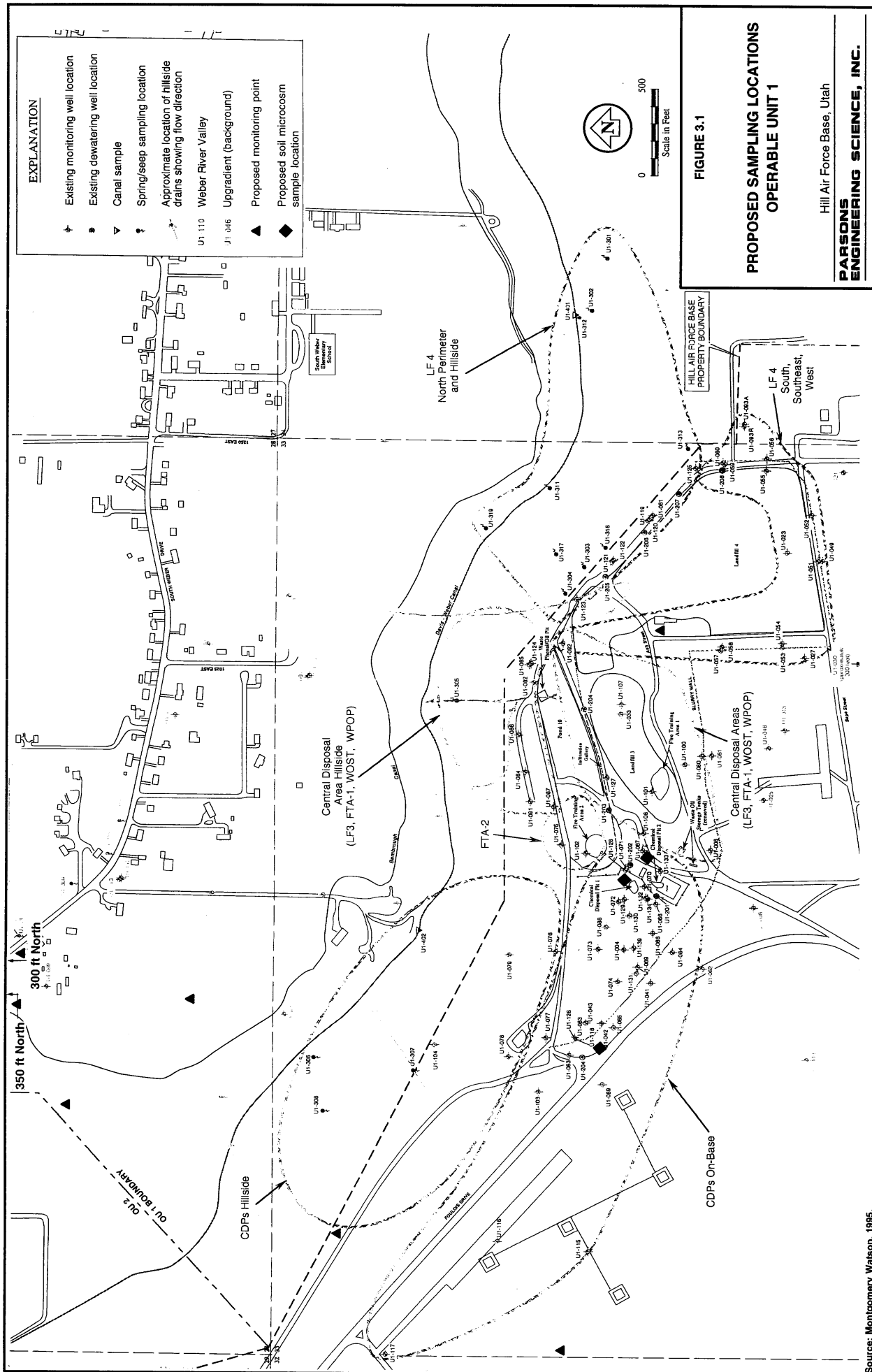


FIGURE 3.1

PROPOSED SAMPLING LOCATIONS OPERABLE UNIT 1

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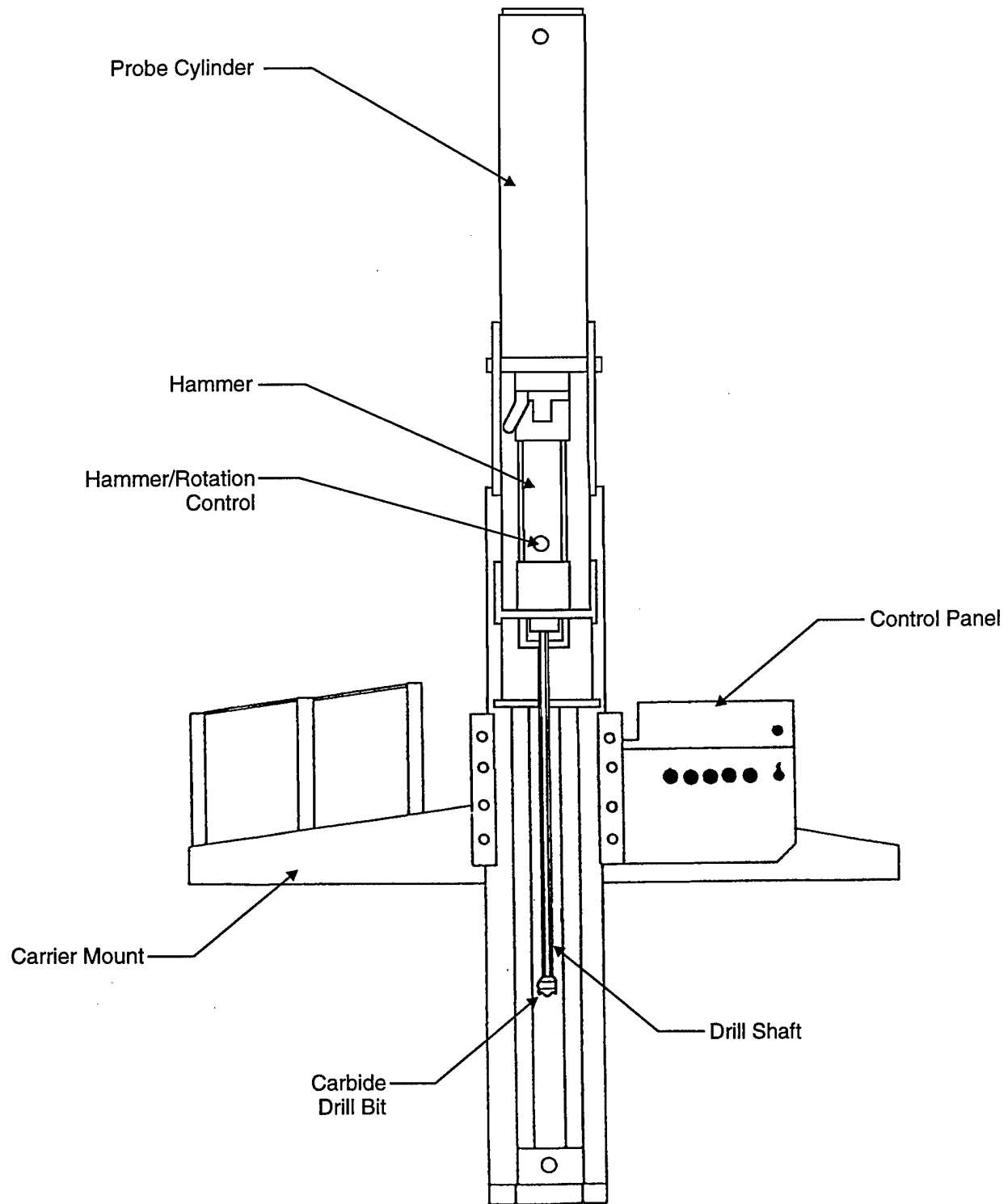


FIGURE 3.2

**CROSS-SECTION
OF GEOPROBE®**

Hill Air Force Base, Utah

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the liners can be cut to the desired length, capped, and submitted to the analytical laboratory for testing of the undisturbed samples.

If the probe-drive sampling technique described above is inappropriate, inadequate, or unable to efficiently provide sufficient soil samples for the characterization of the site, continuous soil samples will be obtained from conventional soil boreholes using a hand auger or similar method judged acceptable by the Parsons ES field scientist. Procedures will be modified, if necessary, to ensure good sample recovery. The Parsons ES field scientist will be responsible for observing all field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, photographing representative samples, and properly labeling and storing samples. An example geologic boring log form is presented as Figure 3.3. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination (as indicated by OVM readings);
- Lithologic description, including relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

Parsons ES will be responsible for identifying the locations of all utility lines, fuel lines, or any other underground infrastructure prior to any sampling activities. All necessary digging permits will be obtained by Parsons ES prior to mobilizing to the field. If necessary, Parsons ES personnel also will be responsible for acquiring drilling and monitoring point installation permits for the proposed locations. Parsons ES and the USEPA NRMRL will provide trained operators for the Geoprobe®.

3.1.3 Datum Survey

The horizontal location of all soil sampling locations relative to established site coordinates will be measured by a surveyor. Horizontal coordinates will be measured to the nearest 0.1 foot. The elevation of the ground surface will also be measured to the nearest 0.1 foot relative to USGS msl data.

3.1.4 Site Restoration

After sampling is complete, each sampling location will be restored as closely to its original condition as possible. Holes created by the Geoprobe® in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive sampler. However, any test holes remaining open after extraction of the push rod will be sealed

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: _____ CONTRACTOR: _____ DATE SPUD: _____
 CLIENT: AFCEE RIG TYPE: _____ DATE CMPL.: _____
 JOB NO.: 729080 DRLG METHOD: _____ ELEVATION: _____
 LOCATION: HILL, AFB BORING DIA.: _____ TEMP: _____
 GEOLOGIST: _____ DRLG FLUID: _____ WEATHER: _____
 COMMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample		Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
					No.	Depth (ft)						
	1											
	5											
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB



Water level drilled

FIGURE 3.3

GEOLOGIC BORING LOG

Hill Air Force Base, Utah

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with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. Soil sampling using the Geoprobe® creates low volumes of soil waste. Soil not retained as samples will be placed in labeled 55-gallon drums provided by the Base. Drum labels will be obtained from Anne Connelly (775-6898). Parsons ES will provide the Base with analytical results that properly characterize soil cuttings.

3.1.5 Equipment Decontamination Procedures

Prior to arriving at the site, and between each sampling location, probe rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

Between each soil sample, the sampling barrel will be disassembled and decontaminated with Alconox® and potable water. The barrel will then be rinsed with deionized water and reassembled with new liners. Between uses, the sampling barrel will be wrapped in clean plastic or foil to prevent contamination.

Potable water to be used during equipment cleaning, decontamination, or grouting will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities. Precautions will be taken to minimize any impact to the surrounding area that might result from decontamination operations. Parsons ES personnel will dispose of all rinseate at the Hill AFB industrial wastewater treatment plant (IWTP).

3.2 MONITORING POINT INSTALLATION

To further characterize site hydrogeologic conditions, up to seven additional groundwater monitoring points (Figure 3.1) will be installed at multiple locations within and adjacent to the OU 1 CAH plume to supplement previously installed site monitoring wells. The following sections describe the proposed monitoring point locations and completion intervals, monitoring point installation, monitoring point development, and equipment decontamination procedures. If site conditions prevent installation of monitoring points, groundwater grab samples will be collected using the Geoprobe® apparatus.

3.2.1 Monitoring Point Locations and Completion Intervals

The locations of the proposed additional soil and groundwater sampling locations are identified on Figure 3.1. The proposed locations for the new monitoring points were determined from a review of data gathered during previous site activities. Monitoring point locations were selected to provide hydrogeologic data necessary for successful implementation of a site-specific contaminant fate and transport model and to monitor potential chlorinated solvent migration from the site. Monitoring point locations were selected to provide additional data on natural attenuation processes in the CAH plume.

The seven proposed locations shown on Figure 3.1 may be modified in the field as a result of encountered field conditions and acquired field data. The points will be placed with the intent of verifying the downgradient plume extent and for collecting additional data from within and upgradient from the plume.

All monitoring points installed for this evaluation will be installed in the shallow aquifer. Monitoring points may be installed singly, or in clusters of up to three points. Single monitoring points will be screened near the top of the saturated zone. All shallow monitoring points will have a screened interval of 3 feet, while deeper points will have 6-inch screens. Monitoring point clusters will include one point screened at the top of the saturated zone, with the exact depth of the remaining monitoring points to be determined by the Parsons ES field scientist on the basis of site conditions. The proposed screened intervals of 3 feet for shallow monitoring points and 6 inches for deep monitoring points will help mitigate the dilution of water samples from potential vertical mixing of contaminated and uncontaminated groundwater in the monitoring point casing. Adjustments of the depth and length of the screened interval of the monitoring points may be necessary in response to actual aquifer conditions and contaminant distribution identified during Geoprobe® testing.

3.2.2 Monitoring Point Installation Procedures

3.2.2.1 Pre-Placement Activities

All necessary utility locates, drilling clearances, and permits will be obtained by Parsons ES personnel prior to mobilizing to the field. In addition, all utility lines will be located, and proposed drilling locations will be cleared prior to any intrusive activities. Responsibilities for these permits and clearances are discussed in Section 3.1.2.

Water to be used in monitoring point installation and equipment cleaning will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities.

3.2.2.2 Monitoring Point Materials Decontamination

Monitoring point installation and completion materials will be inspected by the field scientist and determined to be clean and acceptable prior to use. If not factory sealed, the well points, casing, and tubing will be cleaned prior to use with a high-pressure, steam/hot-water cleaner using approved water. Materials that cannot be cleaned to the satisfaction of the field scientist will not be used.

3.2.2.3 Installation and Materials

This section describes the procedures to be used for installation of monitoring points. Monitoring points will be installed using either 0.375-inch Teflon® tubing

connected to a 0.5-inch-diameter stainless steel screen or a 0.5-inch inside-diameter (ID)/0.75-inch outside-diameter (OD) polyvinyl chloride (PVC) screen and casing.

3.2.2.3.1 Deep Monitoring Points

The deep monitoring points will be installed in boreholes punched using the Geoprobe®. The deep monitoring points will be constructed of a sacrificial drive point attached to a length of 0.5-inch-diameter stainless steel mesh that will function as the well screen, which in turn will be connected to 0.375-inch Teflon® tubing.

To install the deep monitoring points, the borehole is punched and sampled to several feet above the target depth for the monitoring point. The probe rods are withdrawn from the borehole, and the soil sampler is replaced with the well point assembly. An appropriate length of Teflon® tubing is threaded through the probe rods and attached to the well point. The assembly is lowered into the borehole and then driven down to the target depth and sampling zone. The probe rods are removed, leaving the sacrificial tip, screen assembly, and tubing behind. The soil is likely to cave in around the screen and tube assembly; where this does not occur, silica sand will be emplaced to create a sand pack around the well point, and the borehole annular space around the tubing above the sand pack will be filled with granular bentonite or grout to seal it. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.4).

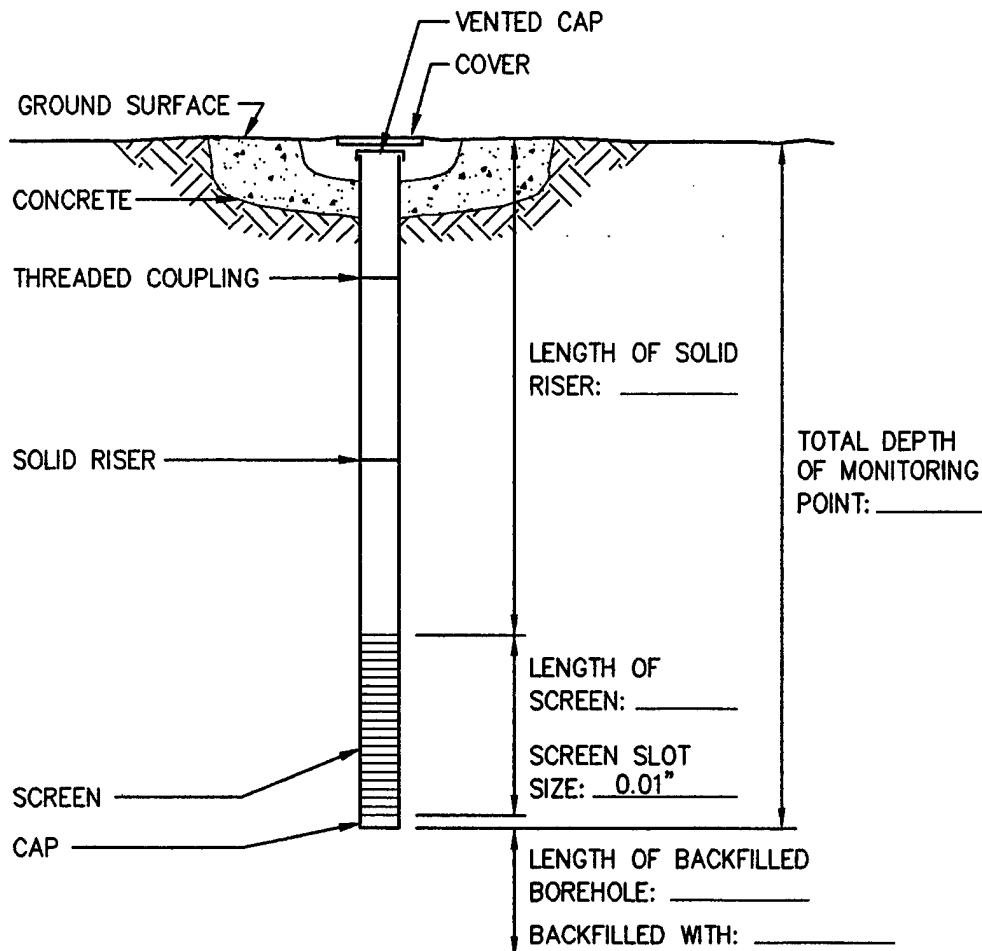
3.2.2.3.2 Shallow Monitoring Points

If subsurface conditions permit, shallow monitoring points will be constructed of 0.75-inch-OD/0.5-inch-ID PVC casing and well screen to provide additional water level information. Approximately 3 feet of factory-slotted screen will be installed for each shallow monitoring point. Shallow 0.5-inch-ID PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe®. Effective installation of the shallow monitoring points requires that the boreholes remain temporarily open after the borehole is punched and the rods are withdrawn. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch-ID PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.4). This information will become part of the permanent field record for the site.

Monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 0.5 inch. The screens will be factory slotted with 0.01-inch openings. Monitoring point screens will be placed to sample and provide water level information at or near the water table. Blank monitoring point casing will be constructed of Schedule 40 PVC with an ID of 0.5 inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC.

MONITORING POINT INSTALLATION RECORD

JOB NAME HILL AIR FORCE BASE MONITORING POINT NUMBER _____
 JOB NUMBER 729080 INSTALLATION DATE _____ LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL _____ SLOT SIZE _____
 RISER DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 CONE PENETROMETER CONTRACTOR _____ ES REPRESENTATIVE _____



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET
 BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.4

MONITORING POINT INSTALLATION RECORD

Hill Air Force Base, Utah

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If subsurface conditions do not permit the boreholes to stay open (i.e., if the formation collapses in the hole), monitoring points constructed of 0.375-inch Teflon® described in Section 3.2.2.3.1 will be installed. Should 0.5-inch-ID PVC shallow monitoring points not be installed, the only resulting data gap will be the lack of water level information for that particular location. The decision to install 0.5-inch-ID PVC monitoring points will be made in the field once the open-hole stability of subsurface soils and Geoprobe® equipment can be evaluated.

The field scientist will verify and record the total depth of the monitoring point, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials. All lengths and depths will be measured to the nearest 0.1 foot.

3.2.2.4 Monitoring Point Completion or Abandonment

A number of the monitoring points will be completed above grade, and as needed, steel or PVC protective casing will be used to protect the well points from tampering and damage. The number of permanent monitoring points will be determined by the Parsons ES field scientist. The completion of the monitoring points will be similar to those protecting the existing monitoring wells unless otherwise specified by Base personnel.

Those monitoring points not completed with an external protective casing will be abandoned. The PVC casing and screen or Teflon® tubing will be extracted as far as possible and discarded. While holes created with the Geoprobe® in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive rod, any test holes remaining open after extraction of the casing will be sealed with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. After monitoring point completion or abandonment, each site will be restored as closely as possible to its original condition.

3.2.3 Monitoring Point Development and Records

The monitoring points will be developed prior to sampling to remove fine sediments from the portion of the formation adjacent to the well point screen. Development will be accomplished using a peristaltic pump provided by USEPA NRMRL or Parsons ES. The pump will be inserted into or attached to the well point, and water will be removed until DO, pH, temperature, and specific conductivity stabilize. Monitoring point development will occur a minimum of 24 hours prior to sampling.

A development record will be maintained for each monitoring point. The development record will be completed in the field by the field scientist. Figure 3.5 is an example of a development record used for similar well installations. Development records will include:

- Monitoring point number;
- Date and time of development;

MONITORING POINT DEVELOPMENT RECORD

Job Number: _____ Job Name: Hill AFB
Location _____ By _____ Date _____
Well Number _____ Measurement Datum TOC

Pre-Development Information

Time (Start): _____

Water Level: _____

Total Depth of Well: _____

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature (°F °C) _____
Specific Conductance (μS/cm) _____

Interim Water Characteristics

Gallons Removed _____

pH _____

Temperature (°F °C) _____

Specific Conductance (μS/cm) _____

Post-Development Information

Time (Finish): _____

Water Level: _____

Total Depth of Well: _____

Approximate Volume Removed: _____

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature (°F °C) _____
Specific Conductance (μS/cm) _____

Comments: _____

FIGURE 3.5

MONITORING POINT DEVELOPMENT RECORD

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- Development method;
- Monitoring point depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and monitoring point depth; and
- Field analytical measurements, including pH and specific conductivity.

Development waters will be collected and held for proper disposal by Base personnel. Alternate methods of water disposal will be considered by the Parsons ES field scientist as recommended by Base personnel.

3.2.4 Monitoring Point Location and Datum Survey

The location and elevation of the well points will be surveyed soon after completion. Horizontal coordinates will be measured to the nearest 0.1 foot relative to established Base coordinates. The elevation of the ground surface adjacent to the protective casing will be measured relative to the USGS msl datum. The ground surface elevation will be measured to the nearest 0.1 foot. A top-of-casing datum will be measured to the nearest 0.01 foot for all monitoring points constructed of 0.5-inch PVC casing and well screen. Because water levels cannot be measured through the well point tubing, no datum elevation, such as top of casing, will be measured for monitoring points constructed with Teflon[®] tubing.

3.2.5 Water Level Measurements

Water levels at existing monitoring wells and 0.5-inch PVC monitoring points will be measured within a short time period so that the water level data are comparable. The depth to water below the measurement datum will be measured to the nearest 0.01 foot using an electric water level probe or an oil/water interface probe.

3.3 GROUNDWATER SAMPLING PROCEDURES

This section describes the scope of work required for collection of groundwater quality samples. Samples will be collected from site monitoring wells (e.g., previously installed wells), newly installed groundwater monitoring points, springs, and at any grab-sample locations. A peristaltic pump or bladder pump with HDPE tubing will be used to collect groundwater samples at all wells and monitoring points. A Grundfos[®] Redi-Flo II[®] pump may be used for monitoring well purging prior to sampling. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

Sampling will be conducted by qualified scientists and technicians from Parson ES and the USEPA NRMRL who are trained in the conduct of groundwater sampling,

records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available onsite for reference. Groundwater sampling includes the following activities:

- Assembly and preparation of equipment and supplies;
- Inspection of the monitoring well/point integrity including:
 - Protective cover, cap, and lock,
 - External surface seal and pad,
 - Monitoring point stick-up, cap, and datum reference, and
 - Internal surface seal;
- Groundwater sampling, including:
 - Water level and product thickness measurements,
 - Visual inspection of sample water,
 - Monitoring point casing evacuation, and
 - Sample collection;
- Sample preservation and shipment, including:
 - Sample preparation,
 - Onsite measurement of physical parameters, and
 - Sample labeling;
- Completion of sampling records: and
- Sample disposition.

Detailed groundwater sampling and sample handling procedures are presented in following sections.

3.3.1 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials will be gathered prior to leaving the office.

3.3.1.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes the Geoprobe® sampling tools, sampling pumps, nondisposable bailers, water level probe and cable, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Given the types of sample analyses to be conducted, the following cleaning protocol will be used:

- Wash with potable water and phosphate-free laboratory detergent (HP-II detergent solutions, as appropriate);
- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling record (Figure 3.6).

If precleaned, disposable sampling equipment is used, the cleaning protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory. The type of container provided and the method of container decontamination will be documented in the USEPA mobile laboratory's permanent record of the sampling event.

3.3.1.2 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturers' specifications prior to field use. This applies to equipment used for onsite measurements of DO, pH, electrical conductivity, temperature, ORP, sulfate, nitrate, ferrous iron, and other field parameters listed on Table 3.1.

3.3.2 Well and Monitoring Point Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The two primary ways in which sample contamination can occur are through contact with improperly cleaned equipment and through cross-contamination due to insufficient cleaning of equipment between wells and monitoring points. To prevent such contamination, the water level probe and cable used to determine static water levels and total well depths will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section 3.3.1.1. Dedicated tubing will be used at each well or monitoring point developed, purged, and/or sampled with the sampling pump. Pumps and nondisposable bailers will be decontaminated according to procedures listed in Section 3.3.1.1. In

Sampling Location Hill AFB

Sampling Dates _____

GROUND WATER SAMPLING RECORD - MONITORING WELL _____

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: _____, 1996 _____ a.m./p.m.

SAMPLE COLLECTED BY: MV/BB of Parsons ES

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOP OF WELL CASING

MONITORING WELL CONDITION:

☐ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH ALCONOX, ISOPROPYL ALCOHOL, AND dH₂O

Items Cleaned (List): _____

2 ☐ PRODUCT DEPTH _____ FT. BELOW DATUM

Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM

Measured with: _____

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: _____

Odor: _____

Other Comments: _____

4 ☐ WELL EVACUATION:

Method: _____

Volume Removed: _____

Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)

Water odors: _____

Other comments: _____

FIGURE 3.6

**GROUNDWATER
SAMPLING RECORD**

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addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile or latex gloves will be worn by the sampling personnel each time a different well or monitoring point is sampled.

The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the field scientist's field notebook or on the groundwater sampling record.

3.3.2.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well/point.

3.3.2.2 Water Level and Total Depth Measurements

Prior to removing water from the monitoring well or PVC-cased monitoring point, the static water level will be measured. An electric water level probe or oil/water interface probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point, and the depth will be measured to the nearest 0.01 foot. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated.

3.3.2.3 Monitoring Well/Point Purging

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and at least three times the calculated volume will be removed from the well/point. A peristaltic pump will be used for monitoring well and monitoring point purging, depth and volume permitting, and a Grundfos Redi-Flo II® pump, Waterra® inertial pump, or bailer will be used to purge all monitoring wells or points in which a peristaltic pump cannot be used. All purge waters will be collected for proper disposal at the Base IWTP.

If a monitoring well/point is evacuated to a dry state during purging, the monitoring well/point will be allowed to recharge, and the sample will be collected as soon as sufficient water is present in the monitoring well/point to obtain the necessary sample quantity. Sample compositing or sampling over a lengthy period by accumulating small volumes of water at different times to obtain a sample of sufficient volume will not be allowed.

3.3.2.4 Sample Extraction

Dedicated HDPE tubing and a peristaltic pump will be used to extract groundwater samples from monitoring wells/points whenever depth to groundwater permits; otherwise, a bladder pump, a Waterra® inertial pump, or a bailer will be used. The tubing, pump, or bailer will be lowered through the casing into the water gently to prevent splashing. The sample will be transferred directly into the appropriate sample container. The water will be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

Unless other instructions are given by the USEPA mobile laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be disposed of in the same manner as purge water.

3.3.2.5 Grab Sampling

In the event monitoring points are not installed, groundwater grab samples will be collected using the Geoprobe® apparatus. To collect these samples, a properly decontaminated, screened probe tip will be driven to the desired sampling depth. As it is driven to depth, the screen will be protected inside the probe rods. After reaching the desired depth, the outer rods will be withdrawn to expose the screen. Purging and sampling procedures will be identical to those for monitoring points. After sampling, the rods and screen will be withdrawn, and the holes will be abandoned as described in Sections 3.1.4 and 3.2.2.4.

3.3.3 Groundwater Sampling at Springs

To determine if CAHs are discharging to the ground surface (and hence creating additional receptor exposure pathways), groundwater emanating from springs and seeps in the study area also will be sampled. Sampling procedures will depend on the manner in which the groundwater discharges to the surface. If possible, sample bottles will be held directly under the discharge area. If a pool of water is present, water will be collected from the bottom of the pool using clean sample jars that will be uncapped underwater. As needed, a jar will be used to transfer water to preserved sample containers. Springs and seeps will not be sampled if sufficient historical surface water quality data are available to allow evaluation of this receptor exposure pathway.

3.3.4 Onsite Groundwater Parameter Measurement

As indicated on Table 3.1, many of the groundwater chemical parameters will be measured onsite by USEPA staff. Some of the measurements will be made with direct-reading meters, while others will be made using a Hach® portable colorimeter in accordance with specific Hach® analytical procedures. These procedures are described in the following subsections.

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of laboratory-grade, phosphate-free detergent (e.g., Alconox[®]) and water, and rinsing with isopropyl alcohol and deionized water to prevent interference or cross-contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric or colorimetric methods, the analysis will be repeated by diluting the groundwater sample with distilled water until the analyte concentration falls to a level within the range of the method. All rinseate and sample reagents accumulated during groundwater analysis will be collected in glass containers fitted with screw caps. These waste containers will be clearly labeled as to their contents and carefully stored for proper disposal.

3.3.4.1 Dissolved Oxygen Measurements

DO measurements will be made using a meter with a downhole oxygen sensor or a sensor in a flow-through cell before and immediately following groundwater sample acquisition. When DO measurements are taken in monitoring wells/points that have not yet been sampled, the existing monitoring wells/points will be purged until DO levels stabilize. The lowest stable DO reading will be recorded.

3.3.4.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected using the same technique as the samples taken for laboratory analyses. The measurements will be made in a flow-through cell or a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded in the groundwater sampling record (Figure 3.6).

3.3.4.3 Oxidation/Reduction Potential

The ORP of groundwater is an indication of the relative tendency of a solution to accept or transfer electrons. Redox reactions in groundwater are usually biologically mediated; therefore, the ORP of a groundwater system depends upon and influences rates of biodegradation. ORPs can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The ORP of a groundwater sample taken inside the contaminant plume should be somewhat less than that taken in an upgradient location.

The ORP of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. Therefore, this parameter will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made as quickly as possible in a clean glass container separate from those intended for laboratory analysis or in a flow-through cell.

3.3.4.4 Alkalinity Measurements

Alkalinity in groundwater helps buffer the groundwater system against acids generated through both aerobic and anaerobic biodegradation processes. Alkalinity of the groundwater sample will be measured in the field by experienced USEPA NRMRL scientists via titrimetric analysis using USEPA-approved Hach® Method 8221 (0 to 5,000 mg/L as calcium carbonate) or a similar method. Alkalinity of the groundwater sample will also be measured in the laboratory using USEPA Method 310.1.

3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements

Nitrate-nitrogen concentrations are of interest because nitrate can act as an electron acceptor during biodegradation under anaerobic soil or groundwater conditions. Nitrate-nitrogen is also a potential nitrogen source for biomass formation for hydrocarbon-degrading bacteria. Nitrite-nitrogen is an intermediate byproduct in both ammonia nitrification and nitrate reduction in anaerobic environments.

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the field by experienced USEPA NRMRL scientists via colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L NO_3^-). Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L NO_2^-) or a similar method. Alternatively, samples may be submitted for laboratory analysis using USEPA Method 353.1 or its equivalent.

3.3.4.6 Sulfate and Sulfide Sulfur Measurements

Sulfate in groundwater is a potential electron acceptor for biodegradation in anaerobic environments, and sulfide is resultant after sulfate reduction. A USEPA NRMRL scientist will measure sulfate and sulfide concentrations via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved Hach® Methods 8051 (0 to 70.0 mg/L SO_4^{2-}) or and 8131 (0.60 mg/L S^{2-}) will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively. Samples also may be submitted for laboratory analysis using a method such as Waters® Capillary Electrophoresis Method N-601 or an equivalent.

3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the ORP of the groundwater and act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. Hach® Method 8008 (or similar) for total soluble iron (0 to 3.0 mg/L $\text{Fe}^{3+} + \text{Fe}^{2+}$) and Hach® Method 8146 (or similar) for ferrous iron (0

to 3.0 mg/L Fe^{2+}) will be used to prepare and quantitate the samples. Ferric iron will be quantitated by subtracting ferrous iron levels from total iron levels.

3.3.4.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantitated in the field using colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L Mn) or similar will be used for quantitation of manganese concentrations. Sample preparation and disposal procedures are outlined earlier in Section 3.3.3.

3.3.4.9 Carbon Dioxide Measurements

Carbon dioxide concentrations are of interest because carbon dioxide is a byproduct of all biodegradation reactions. In addition, carbon dioxide in groundwater is a potential electron acceptor for methanogenic biodegradation under anaerobic conditions. Carbon dioxide concentrations in groundwater will be measured in the field by USEPA NRMRL scientists via titrimetric analysis using Hach® Method 1436-01 (0 to 250 mg/L as CO_2). Sample preparation and disposal procedures are the same as outlined at the beginning of Section 3.3.3.

3.3.4.10 Chloride Measurements

Chloride is a potential byproduct of biologically mediated dehalogenation of CAHs. Chloride concentrations will be quantified in the laboratory either by mercury nitrate titration A-4500- Cl^- -C, Waters® Capillary Electrophoresis Method N-601, ion chromatography method E300 or SW9050, or by silver nitrate titration using a Hach® chloride test kit.

3.4 SAMPLE HANDLING FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to USEPA field laboratory.

3.4.1 Sample Preservation

The USEPA laboratory support personnel will add any necessary chemical preservatives prior to filling the sample containers. Samples will be prepared for transportation to the analytical laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of as close to 4 degrees centigrade ($^{\circ}\text{C}$) as possible. Samples will be delivered promptly to USEPA field laboratory personnel, who will be responsible for shipment of appropriate samples to the NRMRL in Ada, Oklahoma for analysis.

3.4.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the USEPA field laboratory (see Appendix B). The sample containers will be filled as described in

Sections 3.1.2 and 3.3.2.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (e.g., groundwater, soil);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and
- Analyses requested.

3.4.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the onsite USEPA field laboratory. The packaged samples will be delivered by hand to the USEPA field laboratory. Delivery will occur as soon as possible after sample acquisition.

The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Cushion samples to avoid breakage; and
- Add ice to container to keep samples cool.

USEPA personnel will be responsible for repackaging and overnight shipment of samples to the NRMRL in Ada, Oklahoma.

3.4.4 Chain-of-Custody Control

Chain-of-custody documentation for the shipment of samples from the USEPA field laboratory to the NRMRL analytical laboratory in Ada, Oklahoma, will be the responsibility of the USEPA field personnel.

3.4.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the field scientist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
 - Sample appearance, and
 - Sample odor;
- Weather conditions;
- Water level prior to purging (groundwater samples, only);
- Total monitoring well/point depth (groundwater samples, only);
- Sample depth (soil samples, only);
- Purge volume (groundwater samples, only);
- Water level after purging (groundwater samples, only);
- Monitoring well/point condition (groundwater samples, only);
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity (groundwater samples, only); and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.6 is an example of the groundwater sampling record. Soil sampling information will be recorded in the field log book.

3.4.6 Laboratory Analyses

Fixed-base laboratory analyses will be performed on all groundwater and soil samples as well as the QA/QC samples described in Section 4. The analytical methods for this sampling event are listed in Table 3.1. Prior to sampling, USEPA NRMRL personnel will provide a sufficient number of analyte-appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those listed in Appendix B of this plan.

USEPA laboratory support personnel will specify the necessary QC samples and prepare appropriate QC sample containers. For samples requiring chemical preservation, preservatives will be added to containers at the laboratory or by USEPA NRMRL field personnel. Containers, ice chests with adequate padding, and cooling media will be provided by USEPA NRMRL laboratory personnel. Sampling personnel will fill the sample containers and return the samples to the field laboratory.

3.5 AQUIFER TESTING

3.5.1 Slug Tests

Slug tests may be conducted on selected previously installed 2-inch-ID monitoring wells to estimate the hydraulic conductivity of unconsolidated deposits at the site. Alternatively, hydraulic conductivity data obtained during previous investigations may be used. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test; at this site, both methods will be used in sequence.

3.5.1.1 Definitions

- **Hydraulic Conductivity (K).** A quantitative measure of the ability of porous material to transmit water; defined as the volume of water that will flow through a unit cross-sectional area of porous or fractured material per unit time under a unit hydraulic gradient.
- **Transmissivity (T).** A quantitative measure of the ability of an aquifer to transmit water. It is the product of the hydraulic conductivity and the saturated thickness.
- **Slug Test.** Two types of testing are possible: rising head and falling head tests. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.

- **Rising Head Test.** A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing, or removing a submerged slug from the well.
- **Falling Head Test.** A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

3.5.1.2 Equipment

The following equipment will be used to conduct a slug test:

- Teflon[®], PVC, or metal slugs;
- Nylon or polypropylene rope;
- Electric water level indicator;
- Pressure transducer/sensor;
- Field logbook/forms; and
- Automatic data-recording instrument (such as the Hermit Environmental Data Logger[®], In-Situ, Inc. Model SE1000B, or equivalent).

3.5.1.3 General Test Methods

Slug tests are accomplished by either removing a slug or quantity of water (rising head) or introducing a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals.

Because hydraulic testing will be completed on existing wells, it will be assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after multiple water level measurements over time show that static water levels are in equilibrium. During the slug test, the water level change should be influenced only by the introduction (or removal) of the slug volume. Other factors, such as inadequate well development or extended pumping may lead to inaccurate results; in addition, slug tests will not be performed on wells with free product. The field scientist will determine when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of each slug test using the procedures described in Section 3.3.1.1.

3.5.1.4 Falling Head Test

The falling head test is the first step in the two-step slug testing procedure. The following steps describe procedures to be followed during performance of the falling head test.

1. Decontaminate all downhole equipment prior to initiating the test.
2. Open the well. Where wells are equipped with watertight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.
3. Prepare the aquifer slug test data form (Figure 3.7) with entries for:
 - Borehole/well number,
 - Project number,
 - Project name,
 - Aquifer testing team,
 - Climatic data,
 - Ground surface elevation,
 - Top of well casing elevation,
 - Identification of measuring equipment being used,
 - Page number,
 - Static water level, and
 - Date.
4. Measure the static water level in the well to the nearest 0.01 foot.
5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.
6. Lower the decontaminated slug into the well to just above the water level in the well.

Aquifer Slug Test Data Sheet

Location <u>Hill AFB</u>	Client <u>AFCEE</u>	Well No. _____
Job No. _____	Field Scientist _____	Date _____
Water Level _____	Total Well Depth _____	
Measuring Datum <u>TOC</u>	Elevation of Datum _____	
Weather _____	Temp _____	
Comments _____		

[illegible]**FIGURE 3.7**

AQUIFER TEST DATA FORM

Hill Air Force Base, Utah

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7. Turn on the data logger and quickly lower the slug below the water table, being careful not to disturb the pressure transducer. Follow the owner's manual for proper operation of the data logger.
8. Terminate data recording when the water level stabilizes in the well. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.5.1.5 Rising Head Test

After completion of the falling head test, the rising head test will be performed. The following steps describe the rising head slug test procedure.

1. Measure the water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.
2. Initiate data recording and quickly withdraw the slug from the well. Follow the owner's manual for proper operation of the data logger.
3. Terminate data recording when the water level stabilizes in the well, and remove the pressure transducer from the well and decontaminate. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.5.1.6 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV™ (Geraghty & Miller, Inc., 1994) and the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions.

3.5.2 Downhole Flowmeter Testing

Downhole flowmeter tests may be conducted to investigate the relative vertical distribution of horizontal hydraulic conductivity in upper portion of saturated zone and to identify any zones of elevated hydraulic conductivity. To do so, Parsons ES and USEPA personnel may perform electromagnetic borehole flowmeter surveys in up to five previously installed monitoring wells using the methodology of Molz *et al.* (1994). If site conditions allow, these tests will be done to identify any preferential flow pathways that may affect contaminant migration within the shallow aquifer. Site conditions may prevent use of flow meters in areas of particular interest, such as along the hillside north of the OU 1 source areas.

3.5.2.1 Experiment Design

Flowmeter tests, if they are conducted, will be performed at 1- to 3-foot intervals in five test wells during both ambient conditions and induced flow conditions. The test data will be analyzed using the methods described by Molz *et al.* (1994) to define the relative distribution of horizontal hydraulic conductivity within the screened interval of

each well. Final results will be presented in tabular and graphical forms and accompanied by appropriate interpretation and discussion. Estimates of bulk hydraulic conductivity from previous aquifer tests or results of the single-well tests conducted during this survey will be used to estimate the absolute hydraulic conductivity distribution at each well.

3.5.2.2 Procedure

The borehole flowmeter will be calibrated prior to departure for Hill AFB. The 0.5-inch-ID and 1.0-inch-ID probes will be calibrated using a range of volumetric flowrates potentially applicable to this demonstration [e.g., approximately 0.04 liters per minute (L/min) to 10 L/min].

The flowmeter survey will be conducted in each well using the following procedure:

1. Water level, organic liquid (NAPL) interfaces (if present), and total depth (TD) will be measured prior to test initiation.
2. Depending on site conditions, flowmeter measurements using the 0.5-inch-ID probe will be obtained at 1- to 3-foot intervals starting at TD and proceeding up the well under static (ambient) conditions.
3. A short-term, single-well pumping test will be conducted in the test well to stress the aquifer. Drawdown will be measured and recorded using an electronic datalogger with a pressure transducer. The groundwater extraction rate will be monitored and adjusted, as necessary, to maintain constant flow. Groundwater will be contained for disposal by site personnel. It is estimated that extraction rates may range from less than 1 L/min to approximately 10 L/min, and that the test duration may range from 1 to 4 hours.
4. Upon stabilization of the flow rate, the profile of vertical flow will be obtained using the 1.0-inch-ID probe at the same elevations occupied during the ambient profile.
5. Data collected during the tests will be analyzed to estimate relative distribution of flow into the wells and the relative hydraulic conductivity distribution at each location.

All downhole test equipment will be properly decontaminated between tests at different monitoring wells.

3.5.3 Spring Discharge Rate Measurement

Where possible, volumetric rates of groundwater discharge at springs and seeps will also be measured during the field effort. As with sampling of the springs, the method used to determine discharge rates will depend on the nature of the spring. However, if sufficient historical discharge rate data are available, the discharge measurements will not be performed.

3.6 MICROCOSM STUDIES

Microcosm studies may be performed by NRMRL personnel on selected soil samples collected at OU 1 to confirm biodegradation of CAHs and to determine biodegradation pathways. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable uncertainty concerning the biodegradation of CAHs based on soil and groundwater samples alone.

If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of natural bioremediation. They are the only "line of evidence" that allows an unequivocal mass balance on the biodegradation of environmental contaminants. If the microcosm study is properly designed, the results will be easy for decision makers with differing technical backgrounds to interpret. The results of a microcosm study are strongly influenced by the nature of the geological material submitted for the study, the physical properties of the microcosm, the sampling strategy, and the duration of the study.

3.6.1 Microcosm Sample Collection

Saturated soil and groundwater samples for microcosm construction will be collected using the Geoprobe® system. Three potential microcosm sampling locations are shown on Figure 3.1. Ideally, samples collected for microcosms will meet the following conditions: 1) soils and groundwater will be collected minimum of 3 feet below the groundwater surface to minimize oxygen contamination, 2) TCE or DCE concentrations in the groundwater/pore water will be greater than 1 mg/L to guarantee compound resolution throughout the microcosm studies, and 3) only sands or other granular materials should be used for microcosm construction. In the event that soils are highly plastic in the areas selected for microcosm materials collection, additional punches will be performed in the vicinity to locate soils with permeabilities greater than a fine sand. If any of these conditions are not met, microcosm study results may be compromised.

The soil cores will be retained within brass, stainless steel, clear acetate, or Teflon® liners inside the sampling barrel. The soil sample can then be extruded from the liners for logging, or the liners can be capped and undisturbed samples submitted to the analytical laboratory for testing and microcosm construction. Transferring the saturated aquifer media from the soil sampling device will be conducted in a manner that minimizes environmental exposure and to maintain the original physical, chemical, and biological characteristic. The greater the care taken to maintain *in situ* conditions in the microcosm cores, the greater correlation the microcosm data will have to the field scale. The soil sampling device will be retracted quickly from the ground to reduce any potential soil and groundwater loss from the downhole end the sampling apparatus. Furthermore, rapid extraction from the subsurface will help minimize aeration of samples taken from anoxic and anaerobic zones.

Additional groundwater will be collected during soils acquisition. Groundwater will be used to displace the headspace in soil collection jars. Additional groundwater volumes also may be needed for microcosm construction at the USEPA laboratory. Shallow groundwater will be extracted with peristaltic pumps, bailers, or other devices, depending upon site conditions.

All soil and groundwater samples collected in wide-mouth jars will be collected and stored to minimize oxygen contamination. The jars containing site media will be cooled to 4°C and packed in a manner to prevent accidental breakage during shipment. Coolers will be shipped via an overnight courier to be received by the NRMRL laboratory in Ada, Oklahoma the morning following sampling.

3.6.2 Microcosm Construction and Sampling

Personnel from the NRMRL will be responsible for construction and sampling of the microcosms. Standard microcosm procedures, including use of sterilized controls, will be followed to complete this study. These procedures will follow those general procedures outlined at the beginning of Section 3.6.

Batch microcosms that are sacrificed for each analysis usually give more interpretable results than column microcosms or batch microcosms that are sampled repetitively. For statistical reasons, at least three microcosms should be sampled at each time interval. If one assumes a first-order rate law, and no lag, a geometrical time interval for sampling should be the most efficient. An example would be sampling after 0 week, 2 weeks, 1 month, 2 months, 4 months, and 8 months. As a practical matter, long lags frequently occur, and the rate of bioremediation after the lag is rapid; therefore, a simple linear time scale is most likely to give interpretable results. Sampling intervals may be adjusted as the data are collected.

Microcosms are inherently time consuming. At field scale, the residence time of a plume may be several years to decades, and slow rates of transformation may have a considerable environmental significance. A microcosm study that lasts only a few weeks or months may not have the resolution to detect slow changes that are still of environmental significance. Further, microcosms often show a pattern of sequential utilization, with certain contaminants degrading first, and others degrading at a later time. Degradation of some compounds may be delayed by as much as a year.

The batch microcosms should have approximately the same ratio of solids to water as the original material. Most of the microbes are attached to solids. Therefore, if a microcosm has an excess of water, and the contaminant is mostly in the aqueous phase, the microbes must process a great deal more contaminant to produce the same relative change in the contaminant concentration. The kinetics at the field scale would be underestimated.

As a practical matter, batch microcosms with an optimal solids-to-water ratio, sampled every 2 months in triplicate for up to 18 months, can resolve biodegradation losses from abiotic losses with a rate detection limit of 0.001 to 0.0005 per day. Many

plumes show significant attenuation of contamination at field-calibrated rates that are slower than these detection limits. The most appropriate use of microcosms is to document that contaminant attenuation is largely a biological process. Rate constants for modeling purposes are more appropriately acquired from field-scale studies.

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL

Field QA/QC procedures will include collection of field duplicates and rinseate, field and trip blanks; decontamination of all equipment that contacts the sample medium before and after each use; use of analyte-appropriate containers; and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the USEPA laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and sample containers will be packaged in coolers with ice to maintain a temperature of as close to 4°C as possible.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature. Field QC samples will be collected in accordance with the program described below, and as summarized in Table 4.1.

QA/QC sampling will include collection and analysis of duplicate groundwater and replicate soil samples, rinseate blanks, field/trip blanks, and matrix spike samples. Internal laboratory QC analyses will involve the analysis of laboratory control samples (LCSs) and laboratory method blanks (LMBs). QA/QC objectives for each of these samples, blanks, and spikes are described below.

Duplicate water and replicate soil samples will be collected at a frequency of 1 for every 10 or fewer samples of similar matrix. Soil and groundwater samples collected with the Geoprobe sampler should provide sufficient volume for some replicate/duplicate analyses. Refer to Table 3.1 and Appendix B for further details on sample volume requirements.

One rinseate sample will be collected for every 20 or fewer groundwater samples collected from existing wells. Because disposable bailers may be used for this sampling event, the rinseate sample will consist of a sample of distilled water poured into a new disposable bailer and subsequently transferred into a sample container provided by the laboratory. Rinseate samples will be analyzed for VOCs only.

A field blank will be collected for every 20 or fewer groundwater samples (both from groundwater monitoring point and groundwater monitoring well sampling events) to assess the effects of ambient conditions in the field. The field blank will consist of a

TABLE 4.1
QA/QC SAMPLING PROGRAM
Hill Air Force Base, Utah

QA/QC Sample Types	Frequency to be Collected and/or Analyzed	Analytical Methods
Duplicates/Replicates	5 Groundwater and 1 Soil Samples (10%)	VOCs
Rinseate Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Field Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Trip Blanks	One per shipping cooler containing VOC samples	VOCs
Matrix Spike Samples	Once per sampling event	VOCs
Laboratory Control Sample	Once per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	Once per method per medium	Laboratory Control Charts (Method Specific)

sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for VOCs.

A trip blank will be analyzed to assess the effects of ambient conditions on sampling results during the transportation of samples. The trip blank will be prepared by the laboratory. A trip blank will be transported inside each cooler which contains samples for VOC analysis. Trip blanks will be analyzed for VOCs.

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for VOCs. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the site are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits. Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used (see Table 3.1).

SECTION 5

DATA ANALYSIS AND REPORT

Once the data collected during the field effort are assembled, they will be analyzed using a variety of methods. For example, isopleth maps of CAHs, degradation products, and alternate electron acceptors and donors will be used to evaluate the occurrence and mechanisms of biodegradation at the site, using the relationships discussed in Section 2. In addition, the Thiessen method will be used to estimate contaminant mass in the plume, using data from the latest sampling event and from previous sampling events. The Thiessen method also may be used to evaluate movement of the center of mass of the CAH plume over time, as presented by Dupont *et al.* (1996a and 1996b). This information will give an indication of how the plume has changed over time, and whether the plume is stable. If it is apparent that contaminant mass is lost over time, then it is highly likely that biodegradation is occurring. Site contaminant data also will be used to determine rates of contaminant mass loss, and in conjunction with microcosm data, to determine rates of biodegradation. Site data also will be used to estimate contaminant flux through specified areas, and to estimate contaminant flux from the LNAPL, which is a continuing source of dissolved contaminant mass in groundwater. Where possible, the data also will be applied to estimate the impacts of other ongoing or planned remedial actions at the OU 1 area.

After the data evaluation and analysis, numerical and/or analytical groundwater models will be used to evaluate the fate and transport of chlorinated solvents dissolved in groundwater at the site. The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) to provide technical support for selection of RNA as the best remedial alternative at regulatory negotiations, as appropriate.

Based upon model predictions of contaminant concentrations and distribution through time, and upon potential exposure pathways, the potential threat to human health and the environment will be assessed. If it is shown that RNA of CAHs at the site is sufficient to reduce the potential risk to human health and the environment to acceptable levels, Parsons ES will recommend implementation of the RNA option. If RNA is chosen, Parsons ES will prepare a site-specific LTM plan that will specify the location of point-of-compliance monitoring wells and sampling frequencies.

If the RNA remedial option is deemed inappropriate for use at the site, institutional controls such as groundwater or land use restrictions will be evaluated to determine if they will be sufficient to reduce the risk to human health and the environment to acceptable levels. If institutional controls are inappropriate, planned and potential remedial options which could reduce risks to acceptable levels will be evaluated and the most appropriate combination of remedial options will be recommended. Potential remedial options include, but are not limited to, groundwater pump-and-treat, enhanced biological treatment, air sparging, and *in situ* reactive barrier walls. The reduction in dissolved contaminant concentrations that should result from remedial activities will be used to produce new input files for the groundwater models. The models will then be used to predict the plume (and risk) reduction that should result from remedial actions.

A report detailing the results of the modeling and remedial option evaluation will be prepared. This report will follow the outline presented in Table 5.1 and will contain an introduction, site descriptions, identification of remediation objectives, description of remediation alternatives, an analysis of remediation alternatives, and the suggested remedial approach for each site. This report will also contain the results of the site characterization activities described herein.

TABLE 5.1
EXAMPLE REPORT OUTLINE
Hill Air Force Base, Utah

INTRODUCTION

- Scope and Objectives
- Site Background

SITE CHARACTERIZATION ACTIVITIES

- Sampling, Aquifer Testing, and Microcosm Procedures

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

- Surface Features
- Regional Geology and Hydrogeology
- Site Geology and Hydrogeology
- Climatological Characteristics

NATURE AND EXTENT OF CONTAMINATION

- Source Characterization
- Soil and Source Chemistry
 - LNAPL Contamination
 - Residual Contamination
 - Total Organic Carbon
- Groundwater Chemistry
 - Dissolved Contamination
 - Groundwater Geochemistry
- Discussion of Results
 - Evidence of Biodegradation/Cometabolism
 - Calculation of Biodegradation Rates
 - Expressed Assimilative Capacity

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING

- Model Description
- Conceptual Model Design and Assumptions
- Initial Model Setup
- Model Calibration
- Sensitivity Analysis
- Model Results
- Conclusions

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

- Remedial Alternatives Evaluation Criteria
 - Long-Term Effectiveness
 - Implementability (Technical, Administrative)
 - Cost (Capital, Operating, Present Worth)
- Factors Influencing Alternatives Development
 - Program Objectives
 - Contaminant Properties

TABLE 5.1 (continued)
EXAMPLE REPORT OUTLINE
Hill Air Force Base, Utah

Site-Specific Conditions
Brief Description of Remedial Alternatives
 Intrinsic Remediation with Long-Term Monitoring
 Other Alternatives
Evaluation of Alternatives
Recommended Remedial Approach

LONG-TERM MONITORING PLAN

Overview
Monitoring Networks
Groundwater and Surface Water Sampling

CONCLUSIONS AND RECOMMENDATIONS

APPENDICES: Supporting Data and Documentation
 Site-Specific Model Input and Results

SECTION 6

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APPENDIX A

SELECTED PREVIOUS ANALYTICAL DATA

(Compiled from Montgomery Watson, 1995)

SUMMARY OF CHLORINATED AND AROMATIC
HYDROCARBON RESULTS FOR SOILS FROM RADIAN/SAIC (1986)

Analyte (µg/kg)	Soil Boring Depth (ft) Date Sampled	U1-721 12.5-14 5/23/86	U1-721 15-16.5 5/23/86	U1-722 15-16.5 5/23/86	U1-722 18-19.5 5/23/86	U1-723 20-21.5 5/23/86	U1-724 14-14.5 5/23/86	U1-724 20-21.5 5/23/86	U1-725 9-10.5 5/23/86
Tetrachloroethene (Cl)		<0.75	81.2	60	<3.8	38	24219	1750	126
Trichloroethene (Cl)		10.5	70	59.9	419	65.1	92441	1259	562
1,2-Dichloroethene, Total (Cl)		36.7	<13	<13	1096	313	<1300	2896	374
Trichloroethane (Cl)		<22	113	127	111	92	51233	4179	101
1,1-Dichloroethane (Cl)		<1.8	<16	<8.8	<8.8	<16	<1600	48	<8.8
1,4-Dichlorobenzene (Cl)		<50	<30	<8000	<400	<800	<3000	<8000	<800
1,2-Dichlorobenzene (Cl)		<50	<19	<10000	<500	<1000	39159	<10000	575
Chlorobenzene (Cl)		<50	<31	3076	<300	<500	<3100	<5000	<500
Trichlorofluoromethane (Cl)		NA	NA	NA	NA	NA	NA	109	NA
Xylene, Total (FH)		<50	<10000	<10000	2926	4054	<10000	<10000	<1000

Analyte (µg/kg)	Soil Boring Depth (ft) Date Sampled	U1-725 18-19.5 5/23/86	U1-726 14-15.5 5/22/86	U1-726 25-26.5 5/22/86	U1-064 Unknown 5/20/86	U1-068 20-21.5 5/27/86	U1-069 25-26.5 5/28/86	U1-072 20-21.5 5/30/86	U1-082* <3.2 6/26/86
Tetrachloroethene (Cl)		100	44.5	<3.8	<4.4	5.9	<380	<75	23.4
Trichloroethene (Cl)		519	67.5	39.5	7.8	<3.4	<1500	<300	23.4
1,2-Dichloroethene, Total (Cl)		<13	118	347	10.6	<1.3	<1300	<330	59
Trichloroethane (Cl)		431	1455	<68	21.8	<15	<380	<75	8
1,1-Dichloroethane (Cl)		48	<8.8	<16	<0.88	<0.88	<800	<180	<0.88
1,4-Dichlorobenzene (Cl)		<8000	<800	<200	<200	<800	<4000	<4000	<800
1,2-Dichlorobenzene (Cl)		<100	<1000	<300	<300	63	<5000	<5000	<1000
Chlorobenzene (Cl)		<5000	<500	<100	<100	1500	<3000	<3000	78
Trichlorofluoromethane (Cl)		NA	NA	NA	NA	NA	NA	NA	12
Xylene, Total (FH)		<1000	<1000	896	3767	<1000	27228	30185	<1000

* It is unknown whether this boring was sampled before or after the area in the vicinity of Landfill 4 was capped.

Cl Chlorinated hydrocarbon
FH Fuel Hydrocarbon
NA Not analyzed

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT CDPs 1 AND 2
(1 of 3)**

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Volatile Organic Compounds (µg/kg)			
1,1,1-Trichloroethane	Chlorinated Hydrocarbon	1.3 to 8,100	37/88
1,1-Dichloroethane	Chlorinated Hydrocarbon	1.2 to 230	8/88
1,1-Dichloroethene	Chlorinated Hydrocarbon	34 to 790	3/88
1,2,3-Trichlorobenzene	Chlorinated Hydrocarbon	0.99 to 2,900	6/32
1,2,4-Trichlorobenzene	Chlorinated Hydrocarbon	0.06 to 19,000	34/88
1,2,4-Trimethylbenzene	Fuel Hydrocarbon	0.66 to 54,000	21/32
1,2-Dichlorobenzene	Chlorinated Hydrocarbon	1.9 to 170,000	42/88
1,2-Dichloroethane	Chlorinated Hydrocarbon	2.9 to 64	4/88
1,3,5-Trimethylbenzene (Mesitylene)	Fuel Hydrocarbon	0.89 to 20,000	20/32
1,3-Dichlorobenzene	Chlorinated Hydrocarbon	1.0 to 3,200	13/85
1,4-Dichlorobenzene	Chlorinated Hydrocarbon	2.4 to 21,000	37/86
2-Butanone (MEK)	Organic Solvent or Lab Contaminant	1,800 to 5,200(a)	10/56
2-Hexanone	Organic Solvent	8,000	1/56
Acetone	Organic Solvent or Lab Contaminant	7.3 to 1,400(b)	22/56
Benzene	Fuel Hydrocarbon	1.3 to 140 J	4/88
Chlorobenzene	Chlorinated Hydrocarbon	37 to 2,000	9/88
Chloroform	Chlorinated Hydrocarbon	120 J	1/88
Ethylbenzene	Fuel Hydrocarbon	1.2 to 6,200	27/88
Isopropylbenzene (Cumene)	Fuel Hydrocarbon	7.1 to 1,200	5/32
Methyl Isobutyl Ketone	Organic Solvent	4.8 to 6.5	2/45
Methylene Chloride	Chlorinated Hydrocarbon or Lab Contaminant	1.2 to 670(b)	12/88
Naphthalene	Fuel Hydrocarbon	42 to 17,000	33/ 88
Styrene	Fuel Hydrocarbon	1.5	1/88
Tetrachloroethene (PCE)	Chlorinated Hydrocarbon	1.8 to 9,100	37/88
Toluene	Fuel Hydrocarbon	0.92 to 57,000	49/88
Total 1,2-Dichloroethene	Chlorinated Hydrocarbon	3.9 to 14,000	13/56
Trichloroethene (TCE)	Chlorinated Hydrocarbon	1.9 to 40,000	28/88
Xylenes, Total	Fuel Hydrocarbon	8.3 to 51,000	20/56
cis-1,2-Dichloroethene	Chlorinated Hydrocarbon	3.6 to 4,200	19/32
m,p-Xylene	Fuel Hydrocarbon	5.5 to 30,000	19/32
n-Propylbenzene	Fuel Hydrocarbon	770 to 6,000	8/32
o-Xylene (1,2-Dimethylbenzene)	Fuel Hydrocarbon	15 to 12,000	18/32
p-Cymene (p-Isopropyltoluene)	Fuel Hydrocarbon	35 to 4,500	11/32
sec-Butylbenzene	Fuel Hydrocarbon	6.7 to 4,100	8/32

(a) Introduced into sample during analyses (Datachem, 1992)

(b) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for Operable Unit 1* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration

N Frequency of detection (number of detections/number of analyses)

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT CDPs 1 AND 2
(2 of 3)**

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
BNAEs (µg/kg)			
Aniline	Laquer/Wood Stain	1,000	1/56
Phenol	Phenol	1,200 J	1/54
4-Methylphenol (P-Cresol)	Phenol	30 J	1/56
2,4-Dimethylphenol	Phenol	3,500	1/55
2-Methylnaphthalene	Fuel Hydrocarbon	1,200 to 17,000	18/56
Diethylphthalate	Ubiquitous Plasticizer	20 J	1/56
Fluorene	Fuel Hydrocarbon	250 J to 1,400 J	5/56
Phenanthrene	Fuel Hydrocarbon	30 J to 1,800	7/55
Anthracene	Fuel Hydrocarbon	220 J	1/55
Di-n-Butyl Phthalate	Ubiquitous Plasticizer	30 J to 190 J	8/56
Fluoranthene	Fuel Hydrocarbon	50 J to 200 J	7/55
Pyrene	Fuel Hydrocarbon	30 J to 810 J	11/54
Benzyl Butyl Phthalate	Ubiquitous Plasticizer	40 J to 130 J	2/56
Benzo(a)Anthracene	Fuel Hydrocarbon	60 J to 80 J	2/56
Chrysene	Fuel Hydrocarbon	70 J to 380 J	5/56
Bis(2-Ethylhexyl) Phthalate	Ubiquitous Plasticizer or Lab Contaminant	20 J to 14,000(b)	30/56
Di-n-Octyl Phthalate	Ubiquitous Plasticizer	60 J	1/56
Benzo(a)Pyrene	Fuel Hydrocarbon	40 J to 540 J	3/56
Total Petroleum Hydrocarbons (mg/kg)			
Jet Fuel #4	Fuel Hydrocarbon	500 to 42,100	14/88
Jet Fuel #8	Fuel Hydrocarbon	2,700 to 8,600	5/77
Petroleum Hydrocarbons	Fuel Hydrocarbon	14 to 16,000	26/32
Gasoline Components	Fuel Hydrocarbon	1.4 to 2,200	23/77
Pesticides and PCBs (mg/kg)			
Alpha BHC	Pesticide	0.006 to 0.007	2/12
Delta BHC	Pesticide	0.007 to 0.02	2/12
Aldrin	Pesticide	0.003 to 0.02	6/12
Dieldrin	Pesticide	0.007 to 0.015	4/12
p,p'-DDE	Pesticide	0.006 to 0.053	4/12
Endrin	Pesticide	0.005 to 0.073	5/12
Beta Endosulfan	Pesticide	0.005 to 0.2	3/12
p,p'-DDD	Pesticide	0.009 to 0.37	6/12
p,p'-DDT	Pesticide	0.035 to 0.46	2/12
Methoxychlor	Pesticide	0.087 to 1.2	3/12
Endrin Aldehyde	Pesticide	0.14	1/12

(a) Introduced into sample during analyses (Datachem, 1992)

(b) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for Operable Unit 1* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency of detection (number of detections/number of analyses)

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT CDPs 1 AND 2
(3 of 3)**

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Pesticides and PCBs (mg/kg) <continued>			
Alpha-Chlordane	Pesticide	0.005 to 0.016	3/8
PCB-1016 (Arochlor 1016)	PCB	0.15 to 0.29	3/12
PCB-1260 (Arochlor 1260)	PCB	0.07 to 8.3	10/12
Dioxin/Furans (pg/g)			
Tetrachlorinated Dibenzofurans, (Total)	Furan	1.5 to 190	5/5
2,3,7,8-Tetrachlorodibenzofuran	Furan	1.4 to 8.3	3/5
Pentachlorinated Dibenzofurans, (Total)	Furan	57 to 190	3/5
1,2,3,7,8-Pentachlorodibenzofuran	Furan	7.8 to 8.4	2/5
2,3,4,7,8-Pentachlorodibenzofuran	Furan	5.6 to 20	3/5
Hexachlorinated Dibenzofurans, (Total)	Furan	26 to 210	4/5
1,2,3,4,7,8-Hexachlorodibenzofuran	Furan	22 to 55	3/5
1,2,3,6,7,8-Hexachlorodibenzofuran	Furan	6.2 to 16	3/5
2,3,4,6,7,8-Hexachlorodibenzofuran	Furan	5.6 to 20	3/5
1,2,3,7,8,9-Hexachlorodibenzofuran	Furan	6 to 8.1	2/5
Heptachlorinated Dibenzofurans, (Total)	Furan	13 to 370	5/5
1,2,3,4,6,7,8-Heptachlorodibenzofuran	Furan	30 to 140	4/5
1,2,3,4,7,8,9-Heptachlorodibenzofuran	Furan	13 to 26	3/5
Octachlorodibenzofuran	Furan	17 to 310	5/5
Tetrachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	3.6 to 40	4/5
Pentachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	18 to 39	3/5
Hexachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	14 to 150	4/5
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	Dioxin	7.1	1/5
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	Dioxin	7.5 to 20	2/5
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	Dioxin	5.1 to 16	2/5
Heptachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	29 to 840	5/5
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	Dioxin	15 to 480	5/5
Octachlorodibenzo-p-Dioxin	Dioxin	45 to 3,500	5/5
Metals (µg/g)			
Arsenic	Metal	0.8 to 6.6	56/56
Cadmium	Metal	2 to 3	2/50
Chromium	Metal	5 to 62	50/50
Copper	Metal	2 to 200	50/50
Lead	Metal	1 to 860	45/50
Mercury	Metal	0.05 to 0.3	2/56
Zinc	Metal	9 to 79	50/50

(a) Introduced into sample during analyses (Datachem, 1992)

(b) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for Operable Unit 1* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency of detection (number of detections/number of analyses)

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT LANDFILL 3
(1 of 2)**

Analyte (Units)	General Compound Type	Range of - Concentration Detected	N
Volatile Organic Compounds (µg/g or mg/kg)			
1,2,4-Trichlorobenzene	Chlorinated Hydrocarbon	0.13 J to 0.4 J	2/12
1,2-Dichlorobenzene	Chlorinated Hydrocarbon	0.1 J to 0.37 J	3/12
1,3-Dichlorobenzene	Chlorinated Hydrocarbon	0.1 J	1/12
1,4-Dichlorobenzene	Chlorinated Hydrocarbon	0.08 J to 4.2	2/12
2-Butanone (MEK)	Organic Solvent or Lab Contaminant	3.8(a)	1/12
Acetone	Organic Solvent or Lab Contaminant	0.003 to 0.43(a)	8/12
Chlorobenzene	Chlorinated Hydrocarbon	3.9	1/12
Methylene Chloride	Chlorinated Hydrocarbon or Lab Contaminant	0.31(a)	1/12
Naphthalene	Fuel Hydrocarbon	0.041 J	1/12
Toluene	Fuel Hydrocarbon	0.00098 J(a)	1/12
Total 1,2-Dichloroethene	Chlorinated Hydrocarbon	0.028	1/12
Xylenes, Total	Fuel Hydrocarbon	0.0007 J to 0.43	2/12
BNAEs (µg/kg)			
Benzoic Acid	Fuel Hydrocarbon	83 J to 100 J	2/12
2-Methylnaphthalene	Fuel Hydrocarbon	56 J	1/12
Pentachlorophenol	Chlorinated Hydrocarbon	2000	1/12
Phenanthrene	Fuel Hydrocarbon	43 J to 130 J	3/12
Anthracene	Fuel Hydrocarbon	14 J	1/12
Di-n-Butyl Phthalate	Ubiquitous Plasticizer	34 J to 45 J	2/12
Fluoranthene	Fuel Hydrocarbon	24 J to 180 J	3/12
Pyrene	Fuel Hydrocarbon	36 J to 180 J	3/12
Benzo(a)Anthracene	Fuel Hydrocarbon	37 J	1/12
Chrysene	Fuel Hydrocarbon	69 J to 120 J(a)	2/12
Bis(2-Ethylhexyl) Phthalate	Ubiquitous Plasticizer or Lab Contaminant	39 J to 250 J(a)	5/12
Benzo(b)Fluoranthene	Fuel Hydrocarbon	49 J	1/12
Benzo(k)Fluoranthene	Fuel Hydrocarbon	56 J	1/12
Benzo(a)Pyrene	Fuel Hydrocarbon	50 J	1/12
Indeno(1,2,3-C,D)Pyrene	Fuel Hydrocarbon	43 J	1/12
Benzo(g,h,i)Perylene	Fuel Hydrocarbon	40 J	1/12

(a) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for Operable Unit 1* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency of Detection (number of detections/number of analyses)

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT LANDFILL 3
(2 of 2)**

Analyte (Units)	General Compound Type	Range of Concentration Detected	N
Total Petroleum Hydrocarbons (mg/kg)			
Jet Fuel #4	Fuel Hydrocarbon	30	1/12
Pesticides and PCBs (µg/g or mg/kg)			
Aldrin	Pesticide	0.003	1/8
Dieldrin	Pesticide	0.007	1/8
p,p'-DDE	Pesticide	0.007	1/8
p,p'-DDT	Pesticide	0.007	1/8
Alpha-Chlordane	Pesticide	0.003	2/8
PCB-1260 (Arochlor 1260)	PCB	0.07	1/8
Dioxins/Furans (pg/g)			
Tetrachlorinated Dibenzofurans, (Total)	Furan	5 to 14	3/5
Pentachlorinated Dibenzofurans, (Total)	Furan	5.6 to 9.7	3/5
Hexachlorinated Dibenzofurans, (Total)	Furan	6.7 to 12	3/5
Heptachlorinated Dibenzofurans, (Total)	Furan	6.7 to 17	3/5
1,2,3,4,6,7,8-Heptachlorodibenzofuran	Furan	6.8	1/5
Octachlorodibenzofuran	Furan	12	1/5
Tetrachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	2	1/5
Pentachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	5.7	1/5
Hexachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	12	1/5
Heptachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	19 to 50	3/5
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	Dioxin	10 to 26	3/5
Octachlorodibenzo-p-Dioxin	Dioxin	63 to 160	3/5
Metals (µg/g or mg/kg)			
Arsenic	Metal	0.9 to 9.8	10/10
Cadmium	Metal	1 to 2	3/10
Chromium	Metal	6 to 26	10/10
Copper	Metal	5 to 80	10/10
Lead	Metal	2 to 17	10/10
Mercury	Metal	0.08 to 0.1	2/10
Zinc	Metal	9 to 47	10/10

- (a) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for Operable Unit 1* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.
- J Indicates an estimated concentration.
- N Frequency of Detection (number of detections/number of analyses)

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT LANDFILL 4**

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Volatile Organic Compounds (µg/g or mg/kg)			
1,1-Dichloroethane	Chlorinated Hydrocarbon	0.0045 J	1/6
1,2-Dichlorobenzene	Chlorinated Hydrocarbon	0.06 J	1/6
Acetone	Organic Solvent or Lab Contaminant	0.0078 to 0.049(a)	3/6
Benzene	Fuel Hydrocarbon	0.0025 J	1/6
Methylene Chloride	Chlorinated Hydrocarbon or Lab Contaminant	0.0045 J to 0.0061 J(a)	2/6
Tetrachloroethene (PCE)	Chlorinated Hydrocarbon	0.055	1/6
Total 1,2-Dichloroethene	Chlorinated Hydrocarbon	0.003 to 1.6	2/6
Trichloroethene (TCE)	Chlorinated Hydrocarbon	0.0049 J to 0.190	2/5
Vinyl Chloride	Chlorinated Hydrocarbon	0.0045 J	1/6
BNAEs (µg/g or mg/kg)			
2-Methylnaphthalene	Fuel Hydrocarbon	0.11 J	1/6
Phenanthrene	Fuel Hydrocarbon	0.06 J	1/6
Chrysene	Fuel Hydrocarbon	0.4 J	1/6
Benzo(a)Pyrene	Fuel Hydrocarbon	0.41 J	1/6
Total Petroleum Hydrocarbons		None Detected	0/6
Pesticides/PCBs		None Detected	0/3
Dioxins/Furans		None Detected	0/1
Metals (µg/g or mg/kg)			
Arsenic	Metal	0.67 to 5.1	7/7
Beryllium	Metal	0.23 to 0.32	2/7
Chromium	Metal	5.1 to 23	7/7
Copper	Metal	3 to 22	7/7
Lead	Metal	1 to 31	6/7
Zinc	Metal	8 to 57	7/7

(a) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for Operable Unit I* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit I Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency of Detection (number of detections/number of analyses)

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT FIRE TRAINING AREA 1
(1 of 2)**

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Volatile Organic Compounds (µg/kg)			
1,1,1-Trichloroethane	Chlorinated Hydrocarbon	1.4	1/13
1,2,4-Trichlorobenzene	Chlorinated Hydrocarbon	41,000	1/13
1,2-Dichlorobenzene	Chlorinated Hydrocarbon	15,000	1/13
1,3-Dichlorobenzene	Chlorinated Hydrocarbon	520 J	1/13
1,4-Dichlorobenzene	Chlorinated Hydrocarbon	2,600 J	1/13
Acetone	Organic Solvent/Lab Contaminant	7.1 to 3,200(a)	10/13
Acrylonitrile	Lab Contaminant	3,400 to 10,000(a)	2/13
Chlorobenzene	Chlorinated Hydrocarbon	17	1/13
Ethylbenzene	Fuel Hydrocarbon	59 to 3,500	6/13
Methylene Chloride	Chlorinated Hydrocarbon or Lab Contaminant	1.7 to 4.4(a)	3/13
Naphthalene	Fuel Hydrocarbon	340 to 9,900	5/12
Tetrachloroethene (PCE)	Chlorinated Hydrocarbon	11	1/13
Toluene	Fuel Hydrocarbon	0.77 J(a)	1/13
Total 1,2-Dichloroethene	Chlorinated Hydrocarbon	2.2	1/13
Trichloroethene (TCE)	Chlorinated Hydrocarbon	2.2 J	1/13
Xylenes, Total	Fuel Hydrocarbon	1.9 to 37,000	8/13
BNAEs (µg/kg)			
Benzoic Acid	Fuel Hydrocarbon	190 J	1/13
2-Methylnaphthalene	Fuel Hydrocarbon	4,200 to 7,700	3/13
Acenaphthene	Fuel Hydrocarbon	130 J to 270 J	2/13
Fluorene	Fuel Hydrocarbon	360 to 930	2/13
Phenanthrene	Fuel Hydrocarbon	450 to 1400	2/13
Anthracene	Fuel Hydrocarbon	240 J	1 of 13
Di-n-Butyl Phthalate	Ubiquitous Plasticizer	260 J	1/13
Fluoranthene	Fuel Hydrocarbon	65 J	1/13
Pyrene	Fuel Hydrocarbon	100 J to 290 J	2/13
4-Aminobiphenyl	Amine	210 J to 1000	2/13
Total Petroleum Hydrocarbons (mg/kg)			
Jet Fuel #4	Fuel Hydrocarbon	270 to 3,200	7/13
Pesticides and PCBs (mg/kg)			
p,p'-DDE	Pesticide	0.0048 to 0.0065	2/5
p,p'-DDD	Pesticide	0.0042	1/5
p,p'-DDT	Pesticide	0.0048 to 0.33	2/5
PCB-1260 (Arochlor 1260)	PCB	0.072 to 5	2/5

(a) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency of Detection (number of detections/number of analyses)

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT FIRE TRAINING AREA 1
(2 of 2)**

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Dioxin/Furans (pg/g)			
Tetrachlorinated Dibenzofurans, (Total)	Furan	17 to 1,600	5/5
2,3,7,8-Tetrachlorodibenzofuran	Furan	1.6 to 37	4/5
Pentachlorinated Dibenzofurans, (Total)	Furan	21 to 1,100	5/5
1,2,3,7,8-Pentachlorodibenzofuran	Furan	51	1/5
2,3,4,7,8-Pentachlorodibenzofuran	Furan	5 to 100	3/5
Hexachlorinated Dibenzofurans, (Total)	Furan	13 to 580	5/5
1,2,3,4,7,8-Hexachlorodibenzofuran	Furan	9.7 to 75	3/5
1,2,3,6,7,8-Hexachlorodibenzofuran	Furan	6.3 to 50	3/5
2,3,4,6,7,8-Hexachlorodibenzofuran	Furan	6 to 71	3/5
1,2,3,7,8,9-Hexachlorodibenzofuran	Furan	16	1/5
Heptachlorinated Dibenzofurans, (Total)	Furan	11 to 850	5/5
1,2,3,4,6,7,8-Heptachlorodibenzofuran	Furan	8.1 to 350	4/5
1,2,3,4,7,8,9-Heptachlorodibenzofuran	Furan	7.4 to 22	2/5
Octachlorodibenzofuran	Furan	12 to 400	4/5
Tetrachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	11 to 250	4/5
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	Dioxin	7 to 13	3/5
Pentachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	11 to 390	4/5
1,2,3,7,8-Pentachlorodibenzo-p-Dioxin	Dioxin	25 to 42	3/5
Hexachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	34 to 1,800	4/5
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	Dioxin	22 to 50	3/5
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	Dioxin	56 to 220	3/5
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	Dioxin	35 to 120	3/5
Heptachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	21 to 5,700	5/5
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	Dioxin	11 to 3,000	5/5
Octachlorodibenzo-p-Dioxin	Dioxin	83 to 15,000	5/5
Metals (µg/g)			
Arsenic	Metal	0.7 to 4.6	13/13
Beryllium	Metal	1	1/13
Cadmium	Metal	3 to 6	3/13
Chromium	Metal	4 to 52	13/13
Copper	Metal	2 to 120	13/13
Lead	Metal	2 to 150	8/13
Mercury	Metal	0.06 to 0.12	3/13
Zinc	Metal	10 to 96	13/13

(a) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency of Detection (number of detections/number of analyses)

RANGE/ANALYTICAL RESULTS FOR SOIL SLAMPLES
COLLECTED AT FIRE TRAINING AREA 2
(1 of 2)

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Volatile Organic Compounds (µg/kg)			
1,1,1-Trichloroethane	Chlorinated Hydrocarbon	3.9 J	1/18
1,2-Dichlorobenzene	Chlorinated Hydrocarbon	43 J to 50	2/18
Acetone	Organic Solvent or Lab Contaminant	5.4 to 150(a)	8/18
Benzene	Fuel Hydrocarbon	4.5 to 29	2/18
Ethylbenzene	Fuel Hydrocarbon	1,100 to 1,900	3/18
Methylene Chloride	Chlorinated Hydrocarbon or Lab Contaminant	1.2 J(a)	1/18
Naphthalene	Fuel Hydrocarbon	880 J to 5,100	3/18
Total 1,2-Dichloroethene	Chlorinated Hydrocarbon	9.4 to 32	3/18
Trichloroethene (TCE)	Chlorinated Hydrocarbon	17 to 43	2/18
Xylenes, Total	Fuel Hydrocarbon	88 to 12,000	4/18
BNAEs (µg/kg)			
2-Methylnaphthalene	Fuel Hydrocarbon	50 J to 19,000	5/18
Fluorene	Fuel Hydrocarbon	100 J	1/18
Pentachlorophenol	Phenol	120 J	1/18
Phenanthrene	Fuel Hydrocarbon	49 J to 1,400 J	4/18
Di-n-Butyl Phthalate	Ubiquitous Plasticizer	20 J to 53 J	2/18
Fluoranthene	Fuel Hydrocarbon	20 J to 910 J	3/18
Pyrene	Fuel Hydrocarbon	20 J to 690 J	5/18
Chrysene	Fuel Hydrocarbon	40 J	1/18
Bis(2-Ethylhexyl) Phthalate	Ubiquitous Plasticizer or Lab Contaminant	40 J to 50 J(a)	2/18

(a) These data have been qualified and are not considered to be representative/the environment. See the *Final QCSR for Operable Unit 1* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency/Detection (number/detections/number/analyses)

RANGE/ANALYTICAL RESULTS FOR SOIL SLAMPLES
COLLECTED AT FIRE TRAINING AREA 2
(2 of 2)

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Total Petroleum Hydrocarbons (µg/g or mg/kg)			
Jet Fuel #4	Fuel Hydrocarbon	340 to 7,900	4/44
Petroleum Hydrocarbons	Fuel Hydrocarbon	17 to 47,000	28/30
Gasoline Components	Fuel Hydrocarbon	1.2 to 6,900	25/39
Metals (µg/g/mg/kg)			
Arsenic	Metal	1.6 to 10	9/9
Chromium	Metal	7 to 20	9/9
Copper	Metal	4 to 17	9/9
Lead	Metal	4 to 13	9/9
Zinc	Metal	11 to 53	9/9
Soil Characteristics			
Total Organic Carbon (µg/g)	Carbon	1,300 to 13,000	4/4
Moisture (%)	Water	2.6 to 21.9	39/39
Total Volatile Solids (%)	Volatiles	0.4 to 3.9	9/9

(a) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for Operable Unit 1* (Montgomery Watson, 1994) and the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.

J Indicates an estimated concentration.

N Frequency/Detection (number/detections/number/analyses)

RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT THE WPOP
(1 of 2)

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Volatile Organic Compounds (µg/kg)			
1,2,4-Trichlorobenzene	Chlorinated Hydrocarbon	320 J to 4,400	2/3
1,2-Dichlorobenzene	Chlorinated Hydrocarbon	220 J to 540	2/3
1,3-Dichlorobenzene	Chlorinated Hydrocarbon	18 J	1/3
1,4-Dichlorobenzene	Chlorinated Hydrocarbon	36 J to 120 J	2/3
Acetone	Organic Solvent or Lab Contaminant	180 to 2,200(a)	3/3
Total 1,2-Dichloroethene	Chlorinated Hydrocarbon	92	1/3
Trichloroethene (TCE)	Chlorinated Hydrocarbon	560 to 1,400	2/3
BNAEs (µg/kg)			
2,4-Dimethylphenol	Phenol	180 J	1/3
Pentachlorophenol	Phenol	240 J	1/3
Pyrene	Fuel Hydrocarbon	52 J	1/3
Total Petroleum Hydrocarbons (mg/kg)			
Jet Fuel #4	Fuel Hydrocarbon	70	1/3
Pesticides and PCBs (µg/kg)			
p,p'-DDT	Pesticide	7.1	1/3
PCB-1260 (Arochlor 1260)	PCB	80	1/3

- (a) These data have been qualified and are not considered to be representative/the environment. See the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.
- J Indicates an estimated concentration.
- N Frequency of Detection (number of detections/number of analyses).

RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT THE WPOP
(2 of 2)

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Dioxin/Furans (pg/g)			
Tetrachlorinated Dibenzofurans, (Total)	Furan	26	1/2
Pentachlorinated Dibenzofurans, (Total)	Furan	14	1/2
Hexachlorinated Dibenzofurans, (Total)	Furan	9.2	1/2
Heptachlorinated Dibenzofurans, (Total)	Furan	8.7	1/2
1,2,3,4,6,7,8-Heptachlorodibenzofuran	Furan	5.2	1/2
Tetrachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	4.7	1/2
Pentachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	6.8	1/2
Hexachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	20	1/2
Heptachlorinated Dibenzo-p-Dioxins, (Total)	Dioxin	29	1/2
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	Dioxin	14	1/2
Octachlorodibenzo-p-Dioxin	Dioxin	50	1/2
Metals (µg/g)			
Arsenic	Metal	2.6 to 3.4	3/3
Chromium	Metal	8 to 15	3/3
Copper	Metal	11 to 27	3/3
Lead	Metal	7 to 10	3/3
Zinc	Metal	31 to 57	3/3

- (a) These data have been qualified and are not considered to be representative/the environment. See the *Final QCSR for the Phase II Operable Unit I Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.
- J Indicates an estimated concentration.
- N Frequency of Detection (number of detections/number of analyses).

**RANGE OF ANALYTICAL RESULTS FOR SOIL SAMPLES
COLLECTED AT WOST**

Analyte (Units)	General Compound Type	Range of Concentrations Detected	N
Volatile Organic Compounds (µg/kg)			
2-Butanone (MEK)	Organic Solvent or Lab Contaminant	2.75 to 5,400(a)	3/10
Acetone	Organic Solvent or Lab Contaminant	13 to 1,400(a)	3/10
Benzene	Fuel Hydrocarbon	220	1/10
Chlorobenzene	Chlorinated Hydrocarbon	2,800	1/10
Naphthalene	Fuel Hydrocarbon	910	1/7
Toluene	Fuel Hydrocarbon	1.6 to 1200	5/10
Total 1,2-Dichloroethene	Chlorinated Hydrocarbon	6.8 to 13	3/10
Trichloroethene (TCE)	Chlorinated Hydrocarbon	8 to 13	2/10
Xylenes, Total	Fuel Hydrocarbon	5,800	1/10
BNAEs (µg/kg)			
2-Methylnaphthalene	Fuel Hydrocarbon	1,800	1/7
Bis(2-ethylhexyl)phthalate	Ubiquitous Plasticizer or Lab Contaminant	80(a)	1/7
Total Petroleum Hydrocarbons (µg/g or mg/kg)			
Jet Fuel #4	Fuel Hydrocarbon	1,500	1/7
Pesticides and PCBs (µg/g or mg/kg)			
Alpha BHC	Pesticide	0.0016	1/2
Aldrin	Pesticide	0.0047	1/2
p,p'-DDE	Pesticide	0.0005	1/2
Beta Endosulfan	Pesticide	0.038	1/2
p,p'-DDD	Pesticide	0.017	1/2
p,p'-DDT	Pesticide	0.0007 to 0.11	2/2
Methoxychlor	Pesticide	0.26	1/2
PCB-1016 (Arochlor 1016)	PCB	0.19	1/5
PCB-1260 (Arochlor 1260)	PCB	0.025 to 1.9	2/5
Dioxin/Furans (pg/g)		Not Analyzed	
Metals (µg/g or mg/kg)			
Arsenic	Metal	0.8 to 5.3	7/8
Beryllium	Metal	1	1/7
Chromium	Metal	5 to 27	7/8
Copper	Metal	4 to 19	7/7
Lead	Metal	2 to 13	7/8
Zinc	Metal	9 to 65	7/7

- (a) These data have been qualified and are not considered to be representative of the environment. See the *Final QCSR for the Phase II Operable Unit 1 Remedial Investigation* (Montgomery Watson, 1994) for a detailed discussion.
- N Frequency of Detection (number of detections/number of analyses).

**SUMMARY OF VOC, BNAE, PESTICIDE/PCB, DIOXIN/FURAN, AND TPH
RESULTS FOR LNAPL SAMPLES COLLECTED DOWNGRADIENT
OF THE CHEMICAL DISPOSAL PITS DURING THE PHASE II RI
(1 of 2)**

Analytes	Sample ID:	Results	
		M-27-LF	W-4-LF
VOCs (µg/kg)			
Acetone		1,100,000(a)	<43,000
Total 1,2-dichloroethene		<52,500	87,000
1,1,1-Trichloroethane		<27,500	92,000
Tetrachloroethene		<35,000	38,000
Toluene		<35,000	770,000
Chlorobenzene		2,300,000	<13,000
Ethylbenzene		<27,500	210,000
Total xylene		<23,250	1,400,000
BNAEs (µg/kg)			
1,2-Dichlorobenzene		<400,000	2,700,000
Naphthalene		430,000	640,000
2-Methylnaphthalene		<400,000	810,000
bis(2-Ethylhexyl) phthalate		<400,000	730,000(a)
Pesticides/PCBs (µg/ml)			
Aldrin		<0.05	0.41
Alpha-BHC		<0.05	0.15
Dieldrin		<0.05	0.35
Endosulfan Sulfate		3.5	5.3
Endrin		<0.25	0.73
Heptachlor		0.12	0.13
Heptachlor Epoxide		0.41	0.45
PCB-1260		230	190
Dioxin/Furans			
Furans (pg/ml)			
TCDFs (total)		3,800	320
2,3,7,8-TCDF		940 g	11 g

- (a) Based on QCSR for the Phase II OU 1 RI, the datum has been qualified and is not considered representative of the environment
- g 2,3,7,8-TCDF results confirmed on DB-225 column
- J Value is an estimated concentration below the practical quantitation limit
- < Not detected at or above the specified detection limit

µg/kg Microgram per kilogram
mg/ml Milligram per milliliter
µg/ml Microgram per milliliter
pg/ml Picogram per milliliter

ORGANIC COMPOUNDS DETECTED IN GROUNDWATER FROM SELECTED WELLS

Location Date Compounds (ug/L)	UI-062 4/25/90 5/19/93	UI-062 5/16/94	UI-063 5/18/93	UI-063 9/8/93	UI-063 12/10/93	UI-063 2/15/94	UI-063 5/13/94	UI-065 5/1/90	UI-065 5/14/93	UI-065 9/9/93	UI-065 12/1/93	UI-065 2/15/94	UI-065 5/16/94	UI-072 5/16/90	UI-072 5/19/93
Vinyl Chloride			4	<2	2.5	5	1.7T	1800	3300	4600B	4100	4000	200		70J
Chlorobenzene													4900		
1,1-DCE									NS	NS	NS	NS	NS		
trans-1,2-DCE									NS	NS	NS	NS	NS		
cis-1,2-DCE			NS	NS	12	15	NS		NS	NS	NS	NS	NS		
1,1-DCA									NS	NS					
Total 1,2-DCE			15	8.2	NS	NS	10	1400			100	140	160	390D	260
1,2-DCA														9700D	4000
Chloroform															
1,1,1-TCA															
TCE															
PCE															
Benzene															
Toluene															
Ethylbenzene															
Xylenes															

Location Date Compounds (ug/L)	UI-072 9/10/93	UI-072 12/9/93	UI-072 2/18/94	UI-072 6/7/94	UI-073 5/15/90	UI-073 5/14/93	UI-073 12/9/93	UI-073 5/16/94	UI-078 5/1/90	UI-078 5/20/93	UI-078 9/10/93	UI-078 12/3/93	UI-078 2/21/94	UI-078 5/18/94	UI-097 10/23/90	UI-097 10/21/92
Vinyl Chloride																
Chlorobenzene																
1,1-DCE																
trans-1,2-DCE																
cis-1,2-DCE																
1,1-DCA																
Total 1,2-DCE																
1,2-DCA																
Chloroform																
1,1,1-TCA																
TCE																
PCE																
Benzene																
Toluene																
Ethylbenzene																
Xylenes																

ORGANIC COMPOUNDS DETECTED IN GROUNDWATER FROM SELECTED WELLS

Location Date Compounds (ug/L)	U1-097 5/27/93	U1-097 9/14/93	U1-097 11/11/93	U1-097 2/4/94	U1-097 6/15/94	U1-098 10/23/90	U1-098 6/14/93	U1-098 9/15/93	U1-098 11/12/93	U1-098 2/3/94	U1-098 5/10/94	U1-099 10/25/90	U1-099 10/20/92	U1-099 6/8/93
trans-1,2-DCE		.97J	.41T	S.1	.47T									
cis-1,2-DCE				.12T										
1,1-DCA							2.7J	2.2J	3	3.7T	210	3.7		7.7
Total 1,2-DCE						98	170							
1,2-DCA							.62J	.59J	.71T	.86T	.77T			
Chloroform							.93J	.93J	1.3T	1.6T	.94T			
1,1,1-TCA							4.3J	4.3J	5.5	6.6	6			
TCE						2.4								

Location Date Compounds (ug/L)	U1-099 9/15/93	U1-099 11/15/93	U1-099 2/17/94	U1-099 5/12/94	U1-104 12/22/92	U1-104 5/20/93	U1-104 9/9/93	U1-104 12/3/93	U1-104 2/21/94	U1-104 5/18/94	U1-105 1/19/93	U1-105 6/14/93	U1-105 9/15/93	U1-105 11/15/93	U1-105 2/16/94
trans-1,2-DCE	2.2	2.4	29	34				.83T	140	140					
cis-1,2-DCE					43	31	30	35	30	37			580	970	930
1,1-DCA					890	470						8.6J	6.5J	9.4T	9.0T
Total 1,2-DCE															
1,2-DCA					1.8J	2.6J	3.5J	2.6	2.9T	3.2T			1000		
Chloroform						.75J	.61T		.67T						
1,1,1-TCA						.7J	1.1T								
TCE						.60T			.58T				3.5J	5.9T	5.8T

Location Date Compounds (ug/L)	U1-105 5/11/94	U1-108 2/1/93	U1-108 6/14/93	U1-108 9/15/93	U1-108 11/12/93	U1-108 2/7/94	U1-108 6/15/94	U1-112 1/29/93	U1-112 5/26/93	U1-112 9/14/93	U1-112 11/11/93	U1-112 2/3/94	U1-112 5/10/94
trans-1,2-DCE													
cis-1,2-DCE	900	28		330	800	43	190	NS	NS	31	58	93	91
1,1-DCA	7.8T		12J	6.1	17	.80T	3.3T	2.8J	1.7J	.63J	1.2	1.9	1.8
Total 1,2-DCE		1500	670					170	77	NS			
1,2-DCA				.92J	2.3T	.12T	<.5			.11J	.14T	.33T	.33T
Chloroform				2.7J	6.4T	.39T	2.1T			.34T	.59T	.53T	.53T
1,1,1-TCA		14J		4.6J	10	.81T	4.3T	4.1J	2.9J	1.6	2.4	3.2	3.1
TCE	5.2T	28	12UBJ										

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-062 5/19/93	U1-062 9/8/93	U1-062 12/10/93	U1-062 2/17/94	U1-062 5/16/94	U1-062 9/13/94	U1-062 12/5/94	U1-062 3/3/95	U1-062 7/7/95	U1-063 5/18/93	U1-063 9/8/93	U1-063 12/1/93	U1-063 2/15/94	U1-063 5/13/94	U1-063 9/2/94	U1-063 12/5/94
Cations (mg/L)																	
Calcium	26.3	27.9	26.5	25.1	24.8	23.8	25.3	28.2	NA	NA	43.9	45.3	45.3	43.6	47.6	41.8	42.2
Iron	<0.1	<0.1	<0.1	<0.1	173	<100	<100	<100	<100	NA	<100	<100	<100	<100	<100	<100	<100
Magnesium	28.1	26.6	26.4	24.9	24.1	24	23.1	26	NA	NA	30.8	31.8	32.7	30.8	30	29	28.7
Manganese	0.0131	0.0143	0.0142	0.0204	0.0142	0.0131	0.0124	0.0219	NA	NA	0.0181	0.0209	0.0276	0.0212	0.0221	0.0201	0.0196
Potassium	12.3	10.8	13.4	11.3	13.5	11	10.4	10.6	NA	NA	10.6	9.87	10.1	9.98	11.5	10	10.6
Sodium	75.2	62.1	61.6	64.7	71.8	64.9	61.4	66.8	NA	NA	40.9	36.4	39.6	37	36.2	35.3	36.7
Anions (mg/L)																	
Fluoride	<0.2	<0.4	<0.6	<1.6	<1.0	0.39	0.46	0.35	NA	NA	<0.2	<0.40	<1.0	<1.6	<0.8	0.28	0.29
Chloride	49.8	45.4	44.6	66.9	45.2	43.3	41.6	42.7	NA	NA	44.7	40.3	36	40	40.6	38.4	37.4
Sulfate	2	0.96	1.6	7	1.3 UB	1.4	2.3	0.82	NA	NA	18.1	14.3	14.8	16	16.5	17.9	18.8
Alkalinity as Bicarbonate	849	255	267	305	274	310	325	256	NA	NA	274	266	271	334	277	283	286
Nitrate	0.19	<0.10	<0.10	0.98	.13 UB	0.25	<0.10	<0.10	NA	NA	0.15	<0.10	<0.10	0.17 UB	0.12 UB	0.17	<0.10
Total Dissolved Solids (mg/L)	296	318	334	284	361	347	346	316	NA	NA	322	338	336	302	349	342	371
Dissolved Oxygen (mg/L)	NI	7.14	4.32	5.26	6.46	NI	NI	NI	5.84	5.84	NI	6.34	2.02	1.68	0.78	NI	NI
Redox Potential (Eh)	NI	46	60.1	105.6	35.1	NI	NI	NI	21.9	21.9	NI	100	35.6	-440	-92	NI	NI
Turbidity	NI	37	7	10	350	NI	NI	NI	156	156	NI	182	999	999	575	NI	NI
Temperature (Centigrade)	13.8	13.6	12.3	11.3	13.3	NI	NI	NI	13.2	13.2	NI	15	12.1	12.7	13.2	NI	NI
pH	7.46	8.08	7.51	7.83	8.68	NI	NI	NI	8.26	8.26	NI	7.96	8.12	7.21	7.98	NI	NI
Specific Conductivity (umhos/cm)	500	587	670	581	590	NI	NI	NI	579	579	NI	585	598	545	607	NI	NI

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-063 3/3/95	U1-063 6/28/95	U1-065 5/14/93	U1-065 9/9/93	U1-065 12/1/93	U1-065 2/15/94	U1-065 5/16/94	U1-065 8/24/94	U1-065 11/15/94	U1-065 3/3/95	U1-065 7/5/95	U1-072 5/19/93	U1-072 9/10/93	U1-072 12/9/93	U1-072 2/18/94
Cations (mg/L)																
Calcium		44.8	39.3	201	207	202	208	206	199	211	143	173	213	160	132	152
Iron		<100	<100	8.92	12.6	13.9	14.4	16.5	17.7	17.2	9.47	7.83	32.3	27.1	18.3	30.6
Magnesium		31.4	28.3	29.4	30	29.5	28.4	25.8	26.1	29.3	18.8	22.1	43.6	34.5	33.3	36
Manganese		0.022	0.0224	0.459	0.62	0.569	0.492	0.492	0.51	0.559	0.451	0.463	0.928	0.644	0.583	0.705
Potassium		9.96	7.47	3.05	<2.0	<2.0	<2.0	3.05	2.29	3.32	2.32	<2.0	8.12	7	7.27	11.5
Sodium		39.7	34	226	43.1	44.4	37.2	142	142	176	209	65.6	37	29.9	29.6	33.1
Anions (mg/L)																
Fluoride		0.4	0.12	<1.0	<1.0	<1.0	<1.6	<1.0	<1.0	<1.0	<2.0	<1.0	10.6	4.3	3.6	<1.6
Chloride		41.8	36.2	234	60.8	52	84.4	111	180	213	88.3	47.3	79.5	49.1	43.6	53.6
Sulfate		15	17.9	9.2	8	0.28	2	48 UB	1.1	0.93	3.1	1.2	11	1.5	1.0 J	3.7
Alkalinity as Bicarbonate		245	309	789	612	595	601	733	772	764	734	604	642	485	506	602
Nitrate		<4.0	<4.0	<0.10	1.4	<0.10	0.11 UB	<0.10	0.12	<0.10	<0.10	<0.10	<0.10	<0.10	0.11	0.23 UB
Total Dissolved Solids (mg/L)		344	383	1180	814	744	760	929	1000	1090	622	710	1010	658	576	810
Dissolved Oxygen (mg/L)		NI	5.06	NI	1.2	1.4	1.49	1.38	NI	NI	NI	1.06	NI	2.22	2.46	2.6
Redox Potential (Eh)		NI	14.2	NI	-77	38.9	-409.4	151.2	NI	NI	NI	-243.6	NI	-18	-20.3	-112.2
Turbidity		NI	821	NI	15	21	154	4	NI	NI	NI	44	NI	489	210	200
Temperature (Centigrade)		NI	13.5	17.9	14.7	13.4	12.8	12	NI	NI	NI	12.6	12.9	14.5	13.3	11
pH		NI	8.05	6.87	6.81	7.15	6.48	6.56	NI	NI	NI	6.78	6.78	6.78	6.85	6.86
Specific Conductivity (umhos/cm)		NI	567	1800	1280	1240	1290	1640	NI	NI	NI	1240	1300	1110	1150	1060

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-072 3/2/94	U1-072 6/7/94	U1-072 8/18/94	U1-072 12/6/94	U1-072 12/7/94	U1-072 2/21/95	U1-072 6/29/95	U1-073 5/14/93	U1-073 12/9/93	U1-073 5/16/94	U1-073 8/26/94	U1-073 12/6/94	U1-073 2/21/95	U1-073 6/29/95	U1-078 5/20/93
Cations (mg/L)																
Calcium	NA	163	143	NA	NA	234	444	161	231	169	163	141	115	82.4	235	101
Iron	NA	23.5	15.2	NA	NA	4.61	44.6	48.4	43	35.9	25.8	19.5	6.11	0.418	36.6	<0.10
Magnesium	NA	39.5	40.7	NA	NA	55.2	76.5	29.1	43.6	38.2	39.7	40.7	35.6	33.9	42.8	18.5
Manganese	NA	0.96	0.757	NA	NA	1.12	6.23	1.64	1.62	0.687	0.617	0.469	0.305	0.188	1.54	<0.010
Potassium	NA	7.32	8.84	NA	NA	8.96	8.08	6.4	9.1	6.85	8.29	10	7.43	7.75	9.64	<2.0
Sodium	NA	35.8	40.7	NA	NA	44.3	38.8	32.3	33	25	36.5	39.7	37.4	40.1	24	27.4
Anions (mg/L)																
Fluoride	NA	8	2	NA	NA	<2.0	2	0.32	3.8	3.1	<1.0	<1.0	0.78	0.4	0.21	<0.2
Chloride	NA	52.9	57.6	NA	NA	64.8	76.7	47.3	99.3	68.8	59.6	58	59.1	64.1	96.3	38
Sulfate	NA	3.0 UB	68.6	NA	NA	29.7	734	1.2	19.4	3.2 J	4.0 UB	2.2	14.7	24.4	18.6	19.5
Alkalinity as Bicarbonate	NA	562	479	NA	NA	719	614	466	628	498	549	574	444	343	649	310
Nitrate	NA	0.11 UB	<0.10	NA	NA	<0.10	<0.50	0.16	0.17	<0.10	<0.10	0.18	0.3	0.75	0.15	2.7
Total Dissolved Solids (mg/L)	NA	845	899	NA	NA	2810	2620	752	1060	702	690	669	643	542	1280	449
Dissolved Oxygen (mg/L)	3.72	2.84	NI	NI	NI	NI	NI	NI	NI	1.99	1.87	NI	NI	NI	0.89	NI
Redox Potential (Eh)	NA	-86.3	NI	NI	NI	NI	NI	NI	NI	10.5	-43.5	NI	NI	NI	-120.7	NI
Turbidity	586	132	NI	NI	NI	NI	NI	NI	NI	50	275	NI	NI	NI	373	NI
Temperature (Centigrade)	13.7	14.3	NI	NI	NI	NI	NI	NI	14.6	13.4	13.8	NI	NI	NI	14.6	12.7
pH	6.95	6.8	NI	NI	NI	NI	NI	NI	6.64	6.6	6.68	NI	NI	NI	6.62	7.45
Specific Conductivity (umhos/cm)	1130	1150	NI	NI	NI	NI	NI	NI	1300	1260	1120	NI	NI	NI	1630	600

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-078 9/10/93	U1-078 12/3/93	U1-078 2/21/94	U1-078 5/18/94	U1-078 8/26/94	U1-078 11/10/94	U1-078 2/20/95	U1-078 6/26/95	U1-097 5/27/93	U1-097 9/14/93	U1-097 11/11/93	U1-097 2/4/94	U1-097 6/15/94	U1-097 9/7/94	U1-097 12/9/94
Cations (mg/L)																
Calcium	164	189	186	172	127	115	110	122	116	128	116	122	108	102	105	
Iron	<0.10	<0.10	<0.10	0.139	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.427	<0.10	0.348	<0.10	
Magnesium	29.4	32.3	34.2	29.8	24.4	24	21.8	23.2	39	40.2	38.2	40.2	37	33.2	35.2	
Manganese	<0.010	<0.010	<0.010	0.0351	<0.010	<0.010	0.0122	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.0123	<0.010	
Potassium	2.07	2.14	2.42	8.37	15.1	3.6	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	
Sodium	40	48.6	40.3	42.2	34.9	32.6	30.8	37	25.1	28.6	27.8	33.2	26.5	26.8	27.1	
Anions (mg/L)																
Fluoride	<0.4	<1.0	<1.6	<1.0	0.35	0.29	<0.20	<0.10	<0.2	<0.4	0.45	<1.6	<1.0	0.34	0.39	
Chloride	146	160	144	110	60.8	67.8	73.1	102	39.8	50	51.4	46.2	45.6	39.9	39.7	
Sulfate	20.6	21.4	21.9	21.7	21.2	20	18.1	18	47.7	50.5	47.7	49.5	48.6	43.6	39.5	
Alkalinity as Bicarbonate	342	402	512	451	403	374	366	358	298	366	386	386	364	412	444	
Nitrate	3.7	2.5	2.8	2.6 UB	3.5	3.4	2.6	3.7	2.4	4.2	5.9	2.2	4.8	4.5	1.9	
Total Dissolved Solids (mg/L)	698	792	684	633	580	534	512	578	434	590	482	502	602	537	1050	
Dissolved Oxygen (mg/L)	6.48	4.5	4.45	4.91	NI	NI	NI	5.82	NI	7.33	5.3	4.93	6.2	NI	NI	
Redox Potential (Eh)	99	120	194.8	37.4	NI	NI	NI	76.9	NI	103	90.7	176.3	233.5	NI	NI	
Turbidity	16	5	80	150	NI	NI	NI	76	NI	13	5	4	11	NI	NI	
Temperature (Cenigrade)	13	11.3	10.7	12.2	NI	NI	NI	11.1	11.3	14.7	12.1	8.6	9.8	NI	NI	
pH	7.15	7.18	7.19	7.05	NI	NI	NI	7.27	7.12	7.19	7.07	6.65	7.35	NI	NI	
Specific Conductivity (umhos/cm)	1140	1320	1290	1150	NI	NI	NI	923	600	950	877	980	835	NI	NI	

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-097 3/6/95	U1-097 6/20/95	U1-097 7/27/95	U1-098 6/14/93	U1-098 9/15/93	U1-098 11/12/93	U1-098 2/3/94	U1-098 5/10/94	U1-098 9/7/94	U1-098 12/2/94	U1-098 3/6/95	U1-098 6/21/95	U1-099 6/8/93	U1-099 9/15/93	U1-099 11/15/93
Cations (mg/L)																
Calcium		122	121	NA	97	92.4	92.2	94.8	95.3	90.1	106	109	105	98.2	85.2	84.1
Iron		<0.10	<0.10	NA	0.198	<0.10	<0.10	0.745	<0.10	<0.10	<0.10	<0.10	<0.10	0.198	0.184	0.298
Magnesium		40.5	36.2	NA	34.8	32.2	32.5	33.7	32.4	31.4	35.6	36.4	34.8	40.1	33.9	34.1
Manganese		<0.010	<0.010	NA	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.405	0.308	0.245
Potassium		<2.0	<2.0	NA	2.23	2.19	<2.0	<2.0	<2.0	2.21	<2.0	2.05	2.11	36.7	31.7	27.1
Sodium		30	26.5	NA	29.7	31.1	28.3	34.9	32.3	31.3	32.4	32.7	31.4	46	50.5	45.9
Anions (mg/L)																
Fluoride		<0.20	<0.10	NA	0.22	<0.80	<1.0	<2.0	<0.60	0.35	0.41	<0.20	<0.10	0.22	<0.80	<1.0
Chloride		43.8	48.9	NA	40.7	38.3	40.6	36.9	38.3	35.1	36.2	44.8	39.4	51.4	43.5	49.1
Sulfate		39.9	43.7	NA	46.7	37.3	37.4	37.4	38.7	34.6	35.1	39.3	35.4	50	37	41.3
Alkalinity as Bicarbonate		392	392	375	332	313	375	329	317	372	412	351	403	400	368	438
Nitrate		2.8	6.6	NA	7.4	3.9	3.4	3.3	4.2	1.8	3	3.9	2.9	9.2	0.68	1.6
Total Dissolved Solids (mg/L)		528	668	NA	540	480	410	398	414	477	513	43800	524	633	554	474
Dissolved Oxygen (mg/L)		NI	4.57	4.01	NI	4.38	4.7	4.4	4.12	NI	NI	NI	3.7	NI	3.19	3.51
Redox Potential (Eh)		NI	223.7	33.5	NI	125	63.6	202.7	171.2	NI	NI	NI	142.3	NI	60	55.3
Turbidity		NI	11	8	NI	3	4	5	0	NI	NI	NI	5	NI	4	1
Temperature (Centigrade)		NI	10	11.2	14.4	16	10.3	5.4	9.9	NI	NI	NI	11.7	NI	14.7	12.5
pH		NI	6.99	6.86	7.19	7.18	7.08	6.62	7.2	NI	NI	NI	7.13	NI	7.52	7.28
Specific Conductivity (umhos/cm)		NI	886	842	700	740	738	775	735	NI	NI	NI	814	NI	910	847

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-099 2/17/94	U1-099 5/12/94	U1-099 9/9/94	U1-099 12/9/94	U1-099 3/10/95	U1-099 6/22/95	U1-104 5/20/93	U1-104 9/9/93	U1-104 12/3/93	U1-104 2/21/94	U1-104 5/19/94	U1-104 8/26/94	U1-104 11/10/94	U1-104 3/8/95	U1-104 6/26/95
Cations (mg/L)																
Calcium	92.1	99.8	70.9	95	91.9	77.5	106	115	118	115	121	111	101	115	98.8	
Iron	0.264	0.211	0.284	<0.10	0.166	0.198	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	
Magnesium	36.4	38.6	29.8	37.6	34.9	30.2	40.6	44.9	40.5	44.3	41.5	43.4	40.5	42.9	40.7	
Manganese	0.285	0.264	0.21	0.037	0.102	0.235	0.0635	<0.010	0.112	0.0244	0.0442	0.0173	0.0215	<0.010	0.0238	
Potassium	26	28.5	25.8	61.3	32.6	31	3.55	4.15	4.09	4.4	4.46	6.58	3.27	8.82	3.65	
Sodium	49.1	52.1	48.8	43.4	48.3	44.9	40	36.6	37.2	39.8	38.5	55.2	44	41.5	69.2	
Anions (mg/L)																
Fluoride	<1.6	<1.0	0.39	<1.0	0.64	<0.10	<0.2	<1.0	<1.0	<1.6	<1.0	<1.0	0.4	<0.2	0.12	
Chloride	55.8	53.9	39.5	68.9	53.8	40.3	58.5	61.7	64.6	61.5	62.4	73.8	66.4	61.4	60.8	
Sulfate	52.4	54.1	37.6	64.9	43.1	36.8	39.9	36.2	42.1	39.5	38.6	59.6	51.8	43.2	46.6	
Alkalinity as Bicarbonate	382	384	400	404	346	405	402	394	405	485	418	414	447	382	439	
Nitrate	7.4	9.7	0.29	19.8	8	3	2.6	2	1.6	1.3	1.1UB	1.3	1.5	1.2	1.3	
Total Dissolved Solids (mg/L)	542	635	476	1590	570	520	562	604	566	507	571	598	575	642	542	
Dissolved Oxygen (mg/L)	5.52	4.38	NI	NI	NI	4.79	NI	7.7	4.8	5.36	8.25	NI	NI	NI	7.2	
Redox Potential (Eh)	128	-31	NI	NI	NI	-29.7	NI	76	82.4	110.2	86.6	NI	NI	NI	142.6	
Turbidity	0.1	2	NI	NI	NI	10	NI	226	999	999	600	NI	NI	NI	98	
Temperature (Centigrade)	6.1	9.4	NI	NI	NI	10.6	NI	14	11	11.1	12.3	NI	NI	NI	12.5	
pH	7.47	7.46	NI	NI	NI	7.46	NI	7.25	7.45	7.36	7.14	NI	NI	NI	7.34	
Specific Conductivity (umhos/cm)	990	1040	NI	NI	NI	862	NI	960	990	1010	960	NI	NI	NI	905	

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-105 6/14/93	U1-105 9/15/93	U1-105 11/15/93	U1-105 2/16/94	U1-105 5/11/94	U1-105 9/9/94	U1-105 3/9/95	U1-105 6/21/95	U1-108 6/14/93	U1-108 9/15/93	U1-108 11/12/93	U1-108 2/7/94	U1-108 6/15/94	U1-108 9/9/94	U1-108 12/2/94
Cations (mg/L)																
Calcium		81.6	80.8	86.4	76.2	81.8	72.4	82.3	69.5	74.2	89.1	85.2	83.7	64.9	73.5	84.9
Iron		<0.10	<0.10	<0.10	0.133	<0.10	<0.10	0.111	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Magnesium		44.4	42.8	45.5	41.4	43.1	41.2	42	36.3	31.7	34.6	36.8	34.6	28.3	30.6	34.2
Manganese		<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Potassium		10.1	9.77	9.35	8.62	9.87	10.4	9.64	8.13	4.2	4.03	4.22	4.41	3.52	3.92	4.4
Sodium		56.5	54.7	58	58.9	60.9	58.4	61.2	51.7	40.4	36.8	44.8	58.6	32	35.9	49.4
Anions (mg/L)																
Fluoride		0.41	0.7	0.58	<1.6	<0.60	0.58	0.83	0.15	0.22	0.47	<1.0	<1.6	<0.80	0.44	0.45
Chloride		48.3	49.9	59.9	51.7	51.8	46	51.1	48.4	36.4	46.3	52.4	51	32.5	36.3	38.7
Sulfate		45.1	40.3	45.5	44.1	43.1	43.3	44.3	41.9	33.5	30.9	37.1	38.8	30.3	33.1	33.9
Alkalinity as Bicarbonate		404	378	369	399	396	416	381	414	408	327	368	367	293	372	408
Nitrate		0.33	0.35	0.49	0.49 UB	0.44 UB	0.29	0.41	0.43	1.1	1.1	1.2	1.1	0.66 UB	1	0.72
Total Dissolved Solids (mg/L)		552	528	446	488	521	538	594	522	435	472	459	460	374	409	463
Dissolved Oxygen (mg/L)		NI	6.28	4.45	5.77	6.2	NI	NI	4.9	NI	6.35	4.4	4.62	6.08	NI	NI
Redox Potential (Eh)		NI	120	89	197.8	22.2	NI	NI	65.3	NI	146	104.2	-408.1	188	NI	NI
Turbidity		NI	3	4	4	4	NI	NI	5	NI	3	5	72	35	NI	NI
Temperature (Centigrade)		NI	10.7	10.7	10.2	11.3	NI	NI	10.5	NI	13.6	11.2	10.5	10.9	NI	NI
pH		NI	7.39	7.1	7.3	7.29	NI	NI	7.31	NI	7.4	7.28	6.74	7.6	NI	NI
Specific Conductivity (umhos/cm)		NI	851	940	960	940	NI	NI	980	NI	742	810	828	612	NI	NI

GROUNDWATER GEOCHEMICAL DATA FROM SELECTED WELLS

ANALYTES	LOCATION DATE	U1-108 3/9/95	U1-108 6/22/95	U1-112 5/26/93	U1-112 9/14/93	U1-112 11/1/93	U1-112 2/3/94	U1-112 5/10/94	U1-112 9/8/94	U1-112 12/12/94	U1-112 3/10/95	U1-112 6/21/95
Cations (mg/L)												
Calcium		82.5	78.5	99	108	97.3	93.6	108	89.2	128	123	105
Iron		<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Magnesium		33.6	33.8	34.9	35.8	33.1	33.3	35.4	28.9	41.2	37.7	33.8
Manganese		<0.010	<0.010	0.661	0.606	0.341	0.0932	0.596	0.543	0.377	0.466	0.731
Potassium		4.38	4.19	21.2	32.4	24.1	16.4	21.2	30.9	26.3	37.5	31.2
Sodium		47.8	48.7	38.2	38.2	35.5	29.7	34.5	35.9	43	45	37.6
Anions (mg/L)												
Fluoride		0.58	<0.10	<0.2	<0.60	<0.40	<2.0	<1.0	<1.0	<1.0	<0.20	<0.10
Chloride		40.8	44.9	54	58.1	56.1	42.5	56.3	48.2	81.1	67.9	55
Sulfate		36.1	39.1	50.6	51.2	50.4	44.5	51.4	47	56.5	49.8	43.8
Alkalinity as Bicarbonate		322	390	379	349	368	329	364	402	427	398	436
Nitrate		1.2	0.94	2	5.7	3.9	3	5.3	4.2	8.7	4.3	2.9
Total Dissolved Solids (mg/L)		2590	494	585	604	506	466	586	545	693	644	624
Dissolved Oxygen (mg/L)		NI	5.01	NI	2.76	1.31	2.21	1.7	NI	NI	NI	1.41
Redox Potential (Eh)		NI	82.7	NI	118	106.5	157.2	172.1	NI	NI	NI	123.4
Turbidity		NI	11	NI	4	4	5	0	NI	NI	NI	5
Temperature (Centigrade)		NI	11.1	NI	17.2	10.3	4.1	10.4	NI	NI	NI	13.5
pH		NI	7.41	NI	7.23	7.12	6.62	7.18	NI	NI	NI	7.15
Specific Conductivity (umhos/cm)		NI	795	NI	980	865	844	950	NI	NI	NI	941

APPENDIX B

**ANALYTICAL METHODS, DATA USE, AND PACKAGING
REQUIREMENTS FOR SOIL AND GROUNDWATER SAMPLES**

APPENDIX B

ANALYTICAL METHODS, DATA USE, AND PACKAGING REQUIREMENTS FOR SOIL AND GROUNDWATER SAMPLES

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total volatile and extractable hydrocarbons,	Gas chromatography (GC) method SW8015 [modified]	Handbook method; reference is the California LUFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Aromatic and Chlorinated hydrocarbons (BTX, PCE, TCE, DCE, VC)	Purge and trap GC method SW8240	Handbook method modified for field extraction of soil using methanol	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.01–15 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Moisture	ASTM D-2216	Handbook method	Data are used to correct soil sample analytical results for moisture content (e.g., report results on a dry weight basis).	Each soil sampling round	Use a portion of soil sample collected for another analysis	Fixed-base

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, PCE, TCE, DCE, VC, chloromethane, chloroform, other relevant compounds)	Methods SW8010/8020 or SW8240	Handbook methods; analysis may be extended to higher molecular weight alkylbenzenes	Method of analysis for BTEX & CAHs, which are the primary target analytes for monitoring natural attenuation; BTEX & CAH concentrations must also be measured for regulatory compliance; trimethylbenzenes are used to monitor BTEX plume dilution if degradation is primarily anaerobic. Chloromethane and chloroform are indicators of CAH contamination by aerobic pathways.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional)	GC/mass spectroscopy method SW8270; high-performance liquid chromatography method SW8310	Analysis needed only when required for regulatory compliance.	PAHs are components of fuel and are typically analyzed for regulatory compliance; data on their concentrations are not used currently in the evaluation of natural attenuation.	As required by regulations	Collect 1 L of water in a glass container, cool to 4°C	Fixed-base
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell	Field

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H ₂ SO ₄ to pH 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe ⁺²)	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, and nitrate.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Sulfate (SO ₄ ⁻²)	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container, cool to 4°C	Fixed-base
Water	Sulfate (SO ₄ ⁻²)	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect up to 40 mL of water in a glass or plastic container, cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency.	The presence of CH ₄ suggests BTEX or other carbon degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing anaerobic biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H ₂ SO ₄ to pH 2, cool to 4°C	Fixed-base

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Carbon dioxide	Hach test kit model CA-23; Chemetrics Method R-1910	Titrimetric; alternate method	The presence of free CO ₂ dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the CO ₂ concentrations should be compared with background levels to determine if they are elevated; elevated concentrations of CO ₂ could indicate biodegradation of dissolved contaminants.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenolphthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential (ORP)	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field

APPENDIX B (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	pH	Field probe with direct reading meter.	Field	Aerobic and anaerobic processes are pH-sensitive.	Each sampling round	Collect 100-250 mL of water in a glass or plastic container, analyze immediately	Field
Water	Temperature	Field probe with direct reading meter.	Field only	Well development.	Each sampling round	Not Applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100-250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl ⁻ C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system; elevated concentrations may also indicate biodegradation of CAHs.	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base
Water	Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Total Organic Carbon		Laboratory	Used to classify plume and to determine if CAH biodegradation is possible in the absence of anthropogenic carbon.	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

APPENDIX B (concluded)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
ADDITIONAL (OPTIONAL) ANALYSES							
Water	Biochemical Oxygen Demand	EPA Method 405.1			Each sampling round	Collect 2 L of water in a glass container, cool to be determined	Laboratory
Water	Hydrogen (H ₂)		Relatively new analysis; data useful for evaluating biodegradation processes operating at a given time	Indicator of terminal electron-accepting processes operating at a site.	Each sampling round		
Water	Oxygenates (including methanol and acetone)	Optional; SW 8015 Modified			Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Alcohols, ethers, and acetic acids	Optional; SW 8015 Modified		Optional carbon sources for biodegradation.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Acetaldehydes	Optional; GC/MS method to be determined			Each sampling round	to be determined	Laboratory
Water	Aliphatic Fatty Acids	Optional; GC/MS method to be determined		Byproducts of biodegradation processes; indicators of biodegradation and cometabolism.	Each sampling round	to be determined	Laboratory
Water	Organic Acids	Optional; GC/MS method to be determined		Optional carbon sources and byproducts of biodegradation processes.	Each sampling round	to be determined	Laboratory

NOTES:

- * Analyses other than those listed in this table may be required for regulatory compliance.
- 1. "Hach" refers to the Hach Company catalog, 1990.
- 2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
- 3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, USEPA, 1983.
- 4. "Protocols" refers to the AFCEE *Environmental Chemistry Function Installation Restoration Program Analytical Protocols*, 11 June 1992.
- 5. "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)*, September 1993.
- 6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, USEPA, 3rd edition, 1986.
- 7. "ASTM" refers to the *American Society for Testing and Materials*.
- 8. "LUFT" refers to the State of California *Leaking Underground Fuel Tank Field Manual*, 1988 edition.